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Guidelines for Monitoring Indoor Air Quality

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Design considerations are discussed for two types of studies--applied research in indoor air quality and investigations of building-associated problems. A systematic approach for developing the design is also described. In addition, the document presents a format for data reporting and suggestions on quality assurance and quality control.

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GUIDELINES FOR MONITORING INDOOR AIR QUALITY

by

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ABSTRACT

This document provides guidelines for designing programs to measure indoor air quality and associated factors. Brief summaries of past and current research and descriptions of indoor contaminants provide a background for developing the monitoring design. Factors that influence indoor air quality are discussed with the aid of mass balance models. An extensive review of measurement systems, including a listing of numerous instruments with their performance specifications, is presented.

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Niren Nagda and Harry Rector

SECTION 1

INTRODUCTION

PURPOSE

The design of an indoor air quality monitoring program must include considerations not generally required for outdoor monitoring. First, the factors that affect indoor air quality can differ, or at least differ in significance, from those that affect outdoor air quality. For example, indoor sources such as unvented gas appliances have little or no effect on the outdoor air, and the chemical decay of ozone occurs more readily indoors than outdoors. Similarly, although the rate of air exchange between indoors and outdoors through the building envelope has an important effect on indoor air quality, this factor is not important in measuring outdoor air quality. Second, some instruments and measurement methods used to quantify outdoor air quality may not be appropriate for monitoring indoor air quality.

This document offers guidelines to help users design and develop indoor air quality measurement programs. The guidelines apply to nonindustrial indoor environments such as residences, office buildings, schools, retail establishments, and indoor recreational areas. The information provided should assist users in developing monitoring programs for meeting a variety of objectives; examples of typical objectives are given below:

- Characterization of pollutant levels and assessment of responsible factors. Monitoring programs are conducted to characterize levels of indoor pollutants and to examine factors responsible for those levels. This examination of factors can be somewhat qualitative and exploratory, or it can include quantitative assessment and modeling. An example of such a program is monitoring formaldehyde concentrations and examining the dependency of concentration on temperature and structure age. Another example is monitoring various pollutants in selected indoor structures and developing mathematical models for relating the variation in concentrations to time, rate of air exchange, and other parameters.

- Evaluation of impact on indoor air quality. These monitoring programs usually involve "before and after" measurements used to evaluate the impact of various measures designed to conserve energy or alter indoor air quality. Examples of such measures include retrofitting to conserve energy or using devices to improve indoor air quality.

- Exposure assessment. Many individuals spend about 90 percent of their time indoors. Thus, monitoring indoor air quality is useful for assessing human exposure to pollutants. Monitoring data from such studies can also be useful in comparing the indoor contribution of a pollutant with the total exposure and in research to assess health effects.

To a more limited extent, the information in this document will also aid in investigating indoor air quality problems and building-related illnesses. However, this latter area of research is complex and has been investigated mostly through case studies, rather than through a predesigned research program. Suggested solutions or procedures are limited by the current state of the art.

Information presented in this document can help the user to design one component of health-effect studies--namely measurement of pollutant levels. Health-effect-based standards are provided but discussion of the health effects of indoor pollutants are not within the scope of these guidelines. Similarly, this document does not address the design of studies involving chambers and other specialized sampling conditions.

USERS OF THIS DOCUMENT

This document is primarily aimed at users who seek to characterize indoor air quality and the related parameters. These persons may include air pollution specialists; building energy conservation specialists; health department personnel; heating, ventilation, and air conditioning (HVAC) engineers; and undergraduate and graduate students in these and related fields. The guidelines are prepared primarily for those with some knowledge of air pollution monitoring or operation and analysis of building HVAC systems, but with no indoor monitoring experience. Yet parts of the document will be of use to those who are knowledgeable in indoor air quality research. With the aid of this document, users can accomplish the following:

- Develop study design options
- Develop a monitoring design
- Choose from a wide variety of instrumentation and measurement methods tailored to the monitoring objectives
- Use generally accepted quality assurance and quality control principles
- Expand the utility of data collected.

ORGANIZATION OF THE REPORT

This document addresses a variety of topics, which are listed below. For readers who are unfamiliar with indoor air quality, a study of Sections 2 through 5 is suggested as a first step. These users can then focus on specific instrumentation, data reporting, and quality assurance needs presented in Appendixes A and B and in Sections 6 and 7. Those familiar with indoor air quality research can begin with Section 4 and review the instrumentation and methods before referring to Sections 5 and 6. To those who are experts in indoor air quality research, Appendixes A and B may serve as a useful resource.

Section 2--Indoor Air Quality Research

A historical perspective will familiarize the reader with research conducted in the field of indoor air quality. Ongoing research projects are also listed.

Section 3--Pollutants and Other Factors Affecting Indoor Air Quality

Thirteen pollutants or pollutant groups and their indoor sources are summarized. A generalized mass balance model relates various factors affecting indoor concentrations; an example illustrates the use of the model. Publications describing different aspects of indoor air quality research are highlighted.

Section 4--Measurement Systems

This section discusses measurement and instrumentation characteristics, operating principles, and sources of information. Instrumentation and methods for measuring pollutant concentrations and air exchange rates are summarized.

Section 5--Design Considerations

A discussion of various design considerations, including selection of parameters, determination of sample size, and selection of a measurement system, will help the user systematically develop a monitoring program. Helpful hints on such specifics as probe placement are given, and feedback and iterative procedures for developing a design are emphasized. Approaches for addressing building-associated indoor quality problems are discussed.

Section 6--Data Reporting

Guidelines for data reporting will enable users and study investigators to understand the descriptors required to make useful data sets accessible to other users. Formats for reporting the scope and content of data are included.

Section 7--Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) considerations, with references, are discussed.

Appendix A

This appendix categorizes and reviews commercial instruments suitable for measuring indoor air quality.

Appendix B

Standard or accepted methods can be used for certain measurements when no off-the-shelf, commercial instrumentation is available. In some cases, these methods can serve as alternatives to the instrumentation summarized in Appendix A. Appendix B summarizes these methods.

SECTION 2

INDOOR AIR QUALITY RESEARCH

This section provides a brief overview of past and ongoing indoor air quality research. In the case of past research, the section provides the reader with a historical perspective rather than an exhaustive review. A list of some of the ongoing research projects is also included.

HISTORICAL SUMMARY

The first major studies of indoor air quality, conducted in Europe and the United States in the mid-1960s and early 1970s, measured indoor concentrations of outdoor pollutants. Among the pollutants studied were total suspended particles (TSP), sulfur dioxide (SO_2), and carbon monoxide (CO) (Biersteker, DeGraaf, and Nass 1965; Yocom, Clink, and Cote 1971). These early studies, as well as more recent efforts, demonstrated that indoor levels of an outdoor pollutant are affected both by outdoor levels and by indoor generation or removal. For example, indoor concentrations of CO are dependent on outdoor levels and on the extent of emissions from unvented combustion appliances within a structure. On the other hand, in the absence of indoor sources, a pollutant such as ozone (O_3) can rapidly decay indoors. Because of the importance of indoor generation and decay, indoor air quality research quickly expanded to address indoor sources (Cote, Wade, and Yocom 1974) and sinks (Spedding and Rowland 1970).

Although early indoor monitoring studies focused on pollutants governed by ambient air quality standards, the monitoring of contaminants primarily present indoors also began about the same time. For example, an early study to quantify indoor levels of radon (Rn) was undertaken for the U.S. Atomic Energy Commission in the late 1960s and early 1970s (Lowder et al. 1971). Studies in Denmark in the early 1970 (Anderson, Lundquist, and Molhave 1974) also identified formaldehyde (HCHO) as an indoor contaminant.

Infiltration of outside air into a building envelope influences indoor concentrations. Due to difficulties in predicting air infiltration, it has been measured experimentally by employing tracer gas techniques. Initially, air infiltration studies focused on the relation to energy consumption, because air infiltration is an important component of the the heating and cooling loads of buildings. Since the early 1970s, air infiltration has been included as an important facet of indoor air quality monitoring in many studies (Drivas, Simmonds, and Shair 1972).

In early research, the ratio of indoor to outdoor concentrations of some pollutants was thought to be useful in predicting indoor concentrations (Yocom, Clink, and Cote 1971). In the mid-1970s this ratio was replaced by a more fundamental mass balance approach (Shair and Heitner 1974). The mass balance modeling approach, simple in concept, was adapted from odor modeling in industrial hygiene (Turk 1963). In the mass balance approach, described in Section 3, all factors that have an impact on indoor concentration of pollutants, such as rate of indoor generation, are considered in estimating pollutant concentration. In addition to improving predictive capabilities, the mass balance model permits a better understanding of the relation between the various parameters influencing indoor air quality.

The miniaturization of monitoring equipment, which permits pollutant measurements with devices that are readily portable or attachable to clothing, started in the mid-1970s (EPA 1979). In the last 2 to 3 years, the development of such devices has accelerated, and the current state of the art in personal monitoring compares favorably to the technology of larger, stationary monitoring equipment. The advent of personal monitoring has encouraged research on total human exposure that includes measurements at home, at work, outdoors, while commuting, and during other normal daily activities.

Exposure synthesis studies began in 1975 (Fugas 1975). These studies focus on "time budgets," or time spent by population subgroups in various locations. These locations, such as home, work, or travel, are called microenvironments. To synthesize exposure, the data on small, well-characterized ranges of concentrations in a microenvironment can be combined with the time spent in that microenvironment.

Field studies to define actual exposure have been recently initiated. These studies use personal sampling devices and activity logs completed by participants to determine total exposure in the various microenvironments.

Figure 1 depicts the changing emphasis of indoor air quality research.

ONGOING RESEARCH

Table 1 summarizes ongoing research and shows areas of current research emphasis. The table, although not comprehensive, includes many of the typical projects undertaken in the United States in the early 1980s. The projects cover a range of pollutants. In addition to those already named, the pollutants include nitrogen dioxide (NO_2), inhalable particulates (IP), HCHO, Rn, and SO_2. Other studies encompass allergens, volatile organics, and depletion of oxygen (O_2).

Government Agencies sponsor the majority of studies. The Agencies include the EPA, the U.S. Department of Energy (DOE), the Consumer Product Safety Commission (CPSC), the National Institute of Environmental Health Sciences (NIEHS), the Tennessee Valley Authority (TVA), the Bonneville Power Administration (BPA), and New York Energy Research and Development Administration (NYERDA).

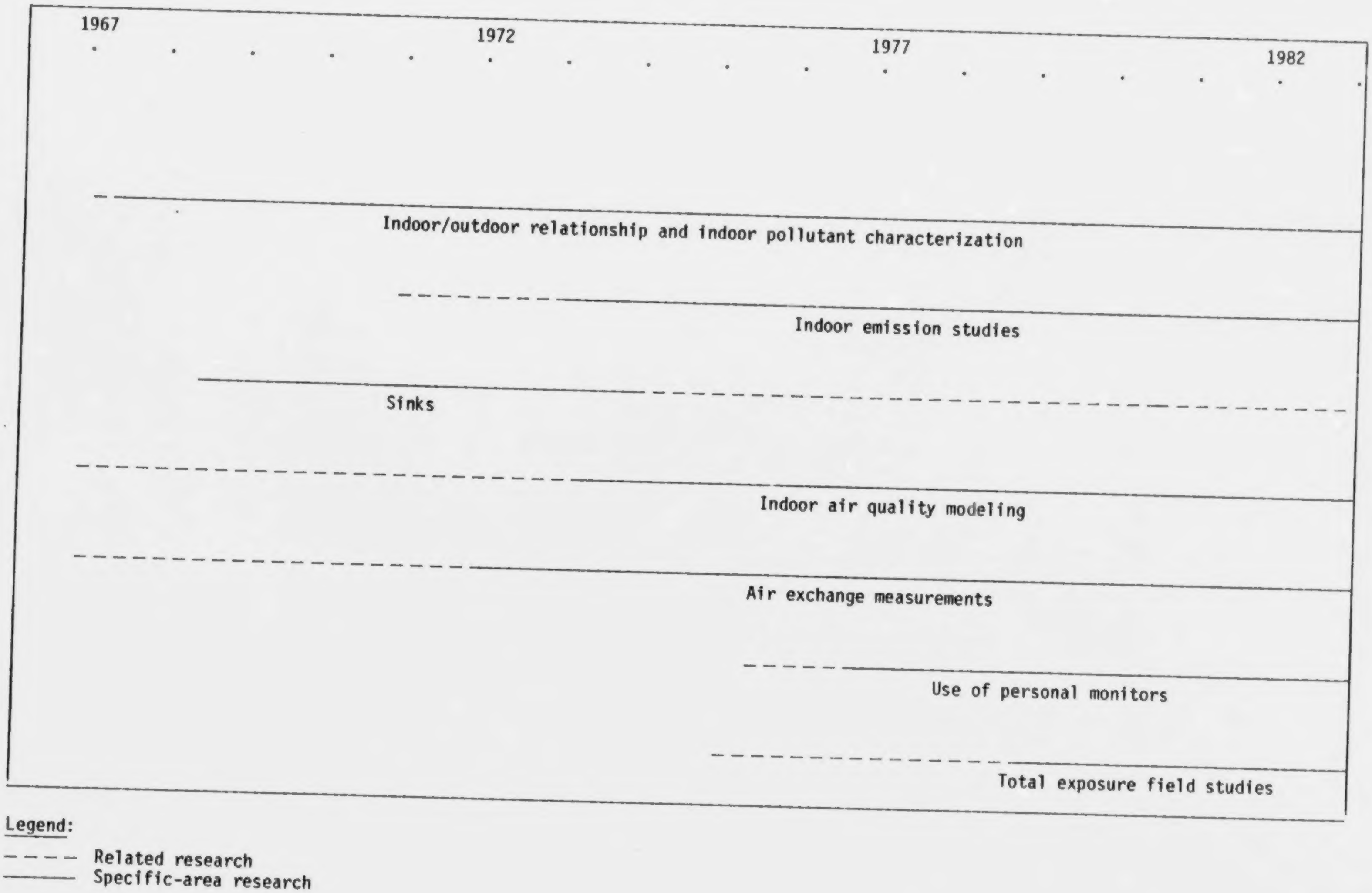

Figure 1. Various aspects of indoor air quality studied during the past 15 years.

TABLE 1. A PARTIAL SUMMARY OF ONGOING RESEARCH RELATED TO INDOOR AIR QUALITY

Area/brief title	Pollutants	Study frame	Sponsoring organization	Principal investigator*
Characterization and Modeling				
Office buildings, homes for elderly, and schools	Organics	Phase I: 1 building each Phase II: 2 buildings each	EPA	Phase I: E. Pellizzari, RTI Phase II: not selected
Air transport within buildings	Rn progeny	3-compartment chamber	DOE	D. Grimsrud, A. Nero, LBL
Monitoring and modeling of energy use, infiltration, and indoor air quality	CO, NO_2, IP, Rn and Rn progeny, HCHO	2 identical houses	EPRI	N.L. Nagda, GEOMET
Pollutants in residential air	CO, NO_2, HCHO, particulates, volatile vapors	40 homes	CPSC	T.G. Matthews, Oak Ridge National Laboratory
Residential and commercial indoor air quality	Rn, NO_2, HCHO, RSP, CO	40 homes for passive monitoring of pollutants; 2 homes subset for real-time	Niagara Mohawk/ NYERDA	R. O'Neil, Niagara Mohawk
Effects of residential woodburning appliances on indoor air quality	CO, CO_2, NO_2, particulates	Test homes	TVA/BPA	J. Harper, TVA
Assessment of natural Rn and Rn progeny in U.S. single-family houses	Rn and Rn progeny	40 representative homes	DOE	J. Rundo, Argonne National Laboratory
Measurement of annual indoor and outdoor ^{222}Rn and its relationship to environmental variables	Rn	Indoor/outdoor; detailed, long-term correlation for a small number of homes	DOE	N. Harley, New York University
Studies of Rn in buildings	Rn	140 homes	DOE	B. Cohen, University of Pittsburgh
Residential ventilation	Rn, HCHO, CO, NO_2	3 pairs of homes, to assess heat exchanger, weatherization, and occupancy	Pacific Power & Light/ Battelle Northwest	D. Zerba, Pacific Power & Light
Influence of building design and other factors on indoor air quality	CO, NO_2, SO_2, O_3, RSP, HCHO	4 homes	NSF	C. Davidson, Carnegie Mellon
Emissions				
Emission from unvented combustion sources; from tobacco combustion; and occupancy and tobacco odor	NO_2, CO, SO_2, CO_2, O_2 depletion; particulates, odor, CO, trace elements, organics; occupancy odor	Chamber	NIEHS	J.A.J. Stolwijk, B.P. Leaderer, W.S. Cain; John B. Pierce Foundation/Yale University

(continued)

* Addresses of principal investigators appear at the end of Table 1.

TABLE 1. (continued)

Area/brief title	Pollutants	Study frame	Sponsoring organization	Principal investigator*
Emission factors for several indoor sources	NO_2, CO, SO_2, CO_2, O_2 depletion	Chamber	NIEHS	J.A.J. Stolwijk, B.P. Leaderer; John B. Pierce Foundation/Yale University
Characterization of emissions from unvented gas stoves, wood stoves, and kerosene heaters	CO, NO_2, SO_2	Research house	DOE and CPSC	D. Grimsrud, A. Nero, LBL
Building materials	Organics	Chamber	DOE	D. Grimsrud, A. Nero, LBL
Characterization of emissions from unvented gas appliances, wood-burning devices, kerosene heaters, cooking, and cigarette smoking	All	Chamber	GRI	D. Moschandreas, IITRI
Emissions from kerosene heaters	CO, CO_2, NO_2, SO_2	Chamber	CPSC	W. Porter, CPSC
Formaldehyde content in various preserved wood products supplied by manufacturers	HCHO	Chemical analysis of wood products	CPSC	T.G. Matthews, Oak Ridge National Laboratory
Controls (Including Ventilation)				
Pollutant-specific removal techniques	Rn, Rn progeny, particulates	3-compartment chamber	DOE	D. Grimsrud, A. Nero, LBL
Behavior of heat exchangers	None	Chamber	DOE EPA, BPA	D. Grimsrud, A. Nero, LBL
Instrumentation				
Development and field evaluation of passive samplers	HCHO, CO, particulates	Laboratory	DOE	D. Grimsrud, A. Nero, LBL
Assessment of radioactive and chemically active air contaminants	Rn, Rn progeny	Develop calibration facility, instrumentation, and methods for residential and public building sampling	DOE	E. Knutson, DOE

(continued)

* Addresses of principal investigators appear at the end of Table 1.

TABLE 1. (concluded)

Area/brief title	Pollutants	Study frame	Sponsoring organization	Principal investigator*
Exposure Studies				
24-hour exposure of residents of Washington, D.C., and Denver	CO	1,000 person-days in each location	EPA	T. Hartwell, RTI; T. Wey, PEDCo
24-hour exposure of residents of chemical-industrial cities	18 volatile organics	500 person-days in two major industrial areas	EPA	E. Pellizzari, RTI
Total exposure to emissions of unvented gas appliances	CO, NO_2	Large multi-pollutant field study	GRI	J. Spengler, Harvard
Characterization of 24-hour exposure of three population subgroups	CO	200 person-days	EPRI	N.L. Nagda, GEOMET
Assessing exposures and adverse health effects associated with alternative heat sources in residences	NO_2, CO, CO_2, SO_2, HCHO, O_2 depletion	Field study	NIEHS/CPSC	J.A.J. Stolwijk, B.P. Leaderer; John B. Pierce Foundation/Yale University
Pollutants, aero-allergens, and respiratory diseases	TSP, RSP, O_3, CO, NO_2, pollen bacilli, fungi, algae	200 homes in 4 geographic clusters	EPA	M.D. Lebowitz, University of Arizona
Data Evaluation				
Evaluation of indoor air quality data for making risk assessments	All	Data from past studies	EPRI	J. Yocom, TRC; J. Spengler, Harvard
Evaluation of risk of exposure to Rn for design of epidemiological studies	Rn and Rn progeny	Data from past studies	DOE	A. Nero, D. Grimsrud, LBL

* Addresses and phone numbers:

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IIT Research Institute, 10 West 35th Street, Chicago, IL 60616, (312) 567-4310.
Lawrence Berkeley Laboratories, University of California, Berkeley, CA 94720, (415) 486-4023.
Niagara Mohawk, 300 Erie Boulevard West, Syracuse, NY 13202, (315) 474-1511.
Oak Ridge National Laboratory, Oak Ridge, TN 37830, (615) 574-6248.
Pacific Power & Light, Portland, OR 97204, (503) 243-4876.
Pierce, John B., Foundation, Yale University, 290 Congress Street, New Haven, CT 06519, (203) 562-9901.
PEDCo Environmental, Inc., 11499 Chester Road, Cincinnati, OH 45246, (513) 782-4700.
Research Triangle Institute, Research Triangle Park, NC 27709, (919) 541-6000.
Tennessee Valley Authority, Chattanooga, TN 37401, (615) 751-0011.
TRC Environmental Consultants, Inc., 800 Connecticut Boulevard, East Hartford, CT 06108, (203) 289-8631.
University of Arizona, University Health Sciences Center, College of Medicine, Tucson, AZ 65724, (602) 626-6379.
U.S. Department of Energy, Environmental Measurements Laboratory, 376 Hudson Street, New York, NY 10014, (212) 620-3570.

Utility organizations sponsor the remainder of the listed indoor research studies. Prominent among these are the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI). Certain utilities such as the Niagara Mohawk Power Company and the Pacific Power & Light Company also support such research.

In general, the ongoing research is aimed at examining important factors influencing indoor air quality, with the possible exception of sink processes. The largest number of projects relate to characterizing indoor air quality. All pollutants known to be important are under study in at least one such project. About half the studies involve a limited number of structures--generally two to three houses. The other half involves larger field studies involving 40-150 structures.

Quantitative determination of emissions is the focus of seven studies. Virtually all indoor sources found in a residential environment are being studied. Five such studies are addressing emissions from unvented space heaters, particularly gas and kerosene heaters. These studies, except for one, are being conducted in chambers or under laboratory conditions.

A small number of studies involve the development of control systems to reduce indoor levels and instrumentation to measure indoor air quality. These are chamber or laboratory studies. The passive monitors, critical to large-scale field studies, have been undertaken for a number of pollutants. With the advent of personal monitors, a number of field studies are being conducted or are planned. Although the majority of field studies involve pollutants such as CO and NO_2, one study involves measuring personal exposure to volatile organics.

In addition, in two studies researchers are evaluating data collected in previous studies to estimate the risk of exposure to various pollutants.

As results of the studies enumerated in Table 1 become available, the data will provide answers to many of the current questions but may fall short of a nationally representative data base. The next generation of studies are likely to involve passive monitoring in large-scale field studies, detailed characterization of contaminant transport within structures, and intensive investigations of indoor air cleaning control systems.

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SECTION 3

INDOOR AIR QUALITY

A number of pollutants can be present in the indoor environment. These pollutants include those generated indoors, and those generated outdoors and migrating indoors. The indoor concentrations of these pollutants are dependent on various factors, including rate of indoor generation and rate of infiltration from outside.

This section provides a summary of information on 13 of the most common indoor pollutants and pollutant groups and the factors that affect indoor air quality. Sources and recommended exposure guidelines are listed (Table 2). A mass balance model relates various factors to indoor concentration levels, and a simple numerical example illustrates use of the mass balance model. Finally in this section, helpful publications are cited and summarized.

POLLUTANTS

Asbestos and Other Fibrous Aerosols

Asbestos, which identifies a group of inorganic silicate mineral fibers, is a widely used component of school, residential, and private and public structures. The indoor release of asbestos depends on the cohesiveness of the asbestos-containing material and the intensity of the distributing force. For example, friable asbestos in the soft or loosely bound form used in fireproofing can become airborne easily by a disturbance of the material surface. Hard asbestos-containing materials such as vinyl floor products release asbestos only upon sanding, grinding, or cutting. Studies show that indoor fiber counts and mass concentrations may exceed those outdoors, and on occasion the levels may approach the occupational standards (2 fibers per ml). During normal use, buildings containing asbestos have not shown higher fiber counts than are found outdoors. Limited data apply mostly to schools and a few office buildings, but the general public exposure to asbestos fibers in public buildings appears to be exceedingly low.

Biological Aerosols

Considerable evidence indicates that a number of contagious disease organisms--including those associated with influenza, Legionnaires' disease, tuberculosis, measles, mumps, and chicken pox--are capable of airborne transmission in the indoor environment. Respiratory diseases such as common colds and pulmonary infections also involve airborne transmission. The transmission occurs when the human respiratory tract emits liquid particles that evaporate to a particle size that can remain airborne for a period of

TABLE 2. SOURCES AND EXPOSURE GUIDELINES OF INDOOR AIR CONTAMINANTS

Pollutant/sources	Guidelines
Asbestos and Other Fibrous Aerosols	
Friable asbestos: fireproofing, thermal and acoustic insulation, decoration. Hard asbestos: vinyl floor and cement products, automatic brake linings (O).[†]	0.2 fibers/ml for fibers longer than 5 μm (based on ASHRAE[*] guidelines of 1/10 of U.S. 8-hour occupational standard).
Biological Aerosols	
Human and animal metabolic activity products, infectious agents, allergens, fungi, bacteria in humidifiers, bacteria in cooling devices.	None available.
Carbon Monoxide	
Kerosene heaters, gas stoves, gas space heaters, wood stoves, fireplaces, smoking, and automobiles (O).	9 ppm for 8 hours (NAAQS[§]); 35 ppm for 1 hour (NAAQS).
Formaldehyde	
Particleboard, paneling, plywood, ceiling tile, urea-formaldehyde foam insulation, other construction materials.	0.1 ppm (based on Dutch and West German guidelines as reported in ASHRAE Guidelines, 1981, and National Research Council report, 1981).
Inhalable Particulates	
Smoking, vacuuming, combustion sources (O), industrial sources, fugitive dust (O), and other organic particulate constituents.	55 to 110 $\mu g/m^3$ annual.[#] 150 to 350 $\mu g/m^3$ for 24 hours.[#]
Metals and Other Inorganic Particulate Contaminants	
Lead: old paint, automobile exhaust (O).	1.5 $\mu g/m^3$ for 3 months (NAAQS).
Mercury: old paint, fossil fuel combustion (O).	2 $\mu g/m^3$ for 24 hours (ASHRAE).
Cadmium: smoking, use of fungicides (O).	2 $\mu g/m^3$ for 24 hours (ASHRAE).
Arsenic: smoking, pesticides, rodent poisons.	None available.
Nitrates: Outdoor air.	None available.
Sulfates: Outdoor air.	4 $\mu g/m^3$ annual, 12 $\mu g/m^3$ for 24 hours (ASHRAE).

(continued)

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[*] ASHRAE--American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[†] (O) refers to outdoor sources.

[§] NAAQS--U.S. National Ambient Air Quality Standards.

[#] These numbers indicate the probable range for the new NAAQS for particulates of 10 μm or less in size. Based on "Recommendations for the National Ambient Air Quality Standards for Particulates--Revised Draft Paper," Strategies and Air Standard Division, Office of Air Programs, EPA, October 1981.

TABLE 2. (concluded)

Pollutant/sources	Guidelines
Nitrogen Dioxide	
Gas stoves, gas space heaters, kerosene space heaters, combustion sources (O), automobile exhaust (O).	0.05 ppm annual (NAAQS).
Ozone	
Photocopying machines, electrostatic air cleaners, outdoor air.	Not exceeding 0.12 ppm once a year (NAAQS).
Pesticides and Other Semivolatile Organics	
Sprays and strips, drift from area applications (O).	5 μg/m^3 for chlordane (NRC).*
Polyaromatic Hydrocarbons and Other Organic Particulate Constituents	
Woodburning, smoking, cooking, coal combustion, and coke ovens (O).	None available.
Radon and Radon Progeny	
Diffusion through floors and basement walls from soil in contact with a residence, construction materials containing radium, untreated groundwater containing dissolved radon, combustion of natural gas used in cooking and unvented heating. Radon from local soil emanation (O).	0.01 working level (ASHRAE guidelines).
Sulfur Dioxide	
Kerosene space heaters, coal and oil fuel combustion sources (O).	80 μg/m^3 annual; 315 μg/m^3 for 24 hours (NAAQS).
Volatile Organics	
Cooking, smoking, room deodorizers, cleaning sprays, paints, varnishes, solvents and other organic products used in homes and offices, furnishings such as carpets and draperies, clothing, furniture, emissions from waste dumps (O).	None available.

* National Research Council. 1982. "An Assessment of Health Risk of Seven Pesticides Used for Termite Control," National Academy Press, Washington, D.C.

time. Natural air currents or convective ventilation flows then transport the particles and deposit them in other human airways. The effect of reduced building ventilation on the incidence of infections is unknown.

Only a few airborne allergens are found in enclosed spaces. A broad array of pollens, fungi, algae, actinomycetes, arthropod fragments, dusts, and pumices are confirmed airborne antigen sources that evoke adverse human responses; evidence is still emerging to implicate airborne bacteria, protozoa, and other groups in a similar manner. Although human exposure to airborne allergens recurs for varying periods of time, no reliable indoor or outdoor concentration data for allergens exist.

Carbon Mononxide

CO originates indoors primarily due to incomplete fuel combustion in gas appliances, wood stoves, unvented space heaters, and tobacco smoke. Automobile emissions originating in attached or underground garages can also be a significant source. CO is essentially nonreactive, and in the absence of indoor sources, average indoor CO concentrations generally compare to outdoor concentrations. But if indoor sources are present, indoor levels can be two or more times greater than those outdoors. Indoor levels can occasionally exceed the 8-hour ambient standard, especially if significant indoor sources are present. Exceedances of the 1-hour standard have not been observed, but sufficient data have not been collected in high-risk environments such as northern city tenements in winter.

Formaldehyde

HCHO, formerly used in insulation, is a component in binders used in commercial wood products. Indoor sources of HCHO include particleboard, plywood, hardwood paneling, furniture, urea formaldehyde foam insulation, tobacco smoke, and gas combustion. Some of the highest concentrations, exceeding 0.1 ppm, have been found in tightly constructed mobile homes where internal volumes are small compared with surface areas of HCHO-containing materials. HCHO emissions increase with increasing temperature and humidity.

Inhalable Particulate Matter

Concentrations of IP matter are determined as mass per unit volume of all particles below a defined aerodynamic diameter, which is commonly 10 μm. Within this size range are two fractions--a coarse fraction of 2.5 to 10 μm and a fine fraction of 0 to 2.5 μm. The fine fraction is associated with alveolar penetration.

Until recently, measurements of particulate matter have centered on TSP matter, with essentially no size selection. Since the late 1970s, determinations have focused upon respirable suspended particulates (RSP) (0 to 15 μm, with corresponding coarse and fine subdivisions at 2.5 μm) and respirable dust (0 to 7.5 μm). It is probably more important to stipulate consideration of particle size than to stipulate the exact size selection.

The fine and coarse fraction of IP have different sources and chemical composition. Fine particles are mainly produced by coagulation of Aitken nuclei (<0.1 μm) and by vapor condensation onto these nuclei. Fine particles typically consist of sulfates, nitrates, ammonium salts, organics, and lead produced by various combustion processes and atmospheric transformations. Coarse particles are mainly produced by mechanical forces such as crushing and abrasion. Generally, these particles consist of finely divided minerals such as oxides of silicon, iron, and aluminum; plant, animal, and insect fibers; tire particles; and sea salt.

Chemical analyses of IP suggest that indoor and outdoor compositions differ, indicating that the building envelope acts as a barrier to outdoor sources. However, indoor IP mass may exceed outdoor levels, indicating that indoor sources such as smoking, other combustion, and reentrained dust are important determinants for indoor concentrations.

Metals and Other Inorganic Particulate Constituents

Metals found in the indoor environment include heavy elemental substances such as lead (Pb), mercury (Hg), and arsenic (As). These substances are components of the particulate matter discussed elsewhere in this section. Evidence indicates that these metals have no significant indoor sources. One exception, however, is lead, which contaminates old, low-income housing when the feet of occupants grind peeling lead-base paint into small-size particles. In addition, smoking and the use of some pesticides contribute to indoor levels of heavy trace metals such as arsenic and cadmium. Reentrainment is another possible indoor source when dust and particles enter a building either through infiltration or by being brought in by footwear.

Other inorganic constituents include sulfates and nitrates. Information on indoor generation of sulfates and nitrates is not available.

Nitrogen Dioxide

NO_2 sources are the same as those for CO, but NO_2 emissions result from high-temperature fuel combustion, whereas CO results from incomplete combustion. NO_2 is a relatively reactive gas. In the absence of indoor sources, indoor NO_2 levels are usually equal to or somewhat lower than outdoor concentrations. If indoor sources are present, indoor NO_2 concentrations can exceed outdoor levels by a factor of five or more. Short-term (1-hour or 24-hour) indoor NO_2 concentrations in residences with indoor sources can also exceed the annual NAAQS of 0.05 ppm.

Ozone

In most cases, the source of indoor O_3 is ambient air. Exceptions include certain types of office copying machines and air cleaners that work on electrostatic principles. O_3 decays very rapidly indoors. The half-life period for O_3, or the time required to reduce to one-half of the original concentration, is less than 30 minutes. Thus, high indoor O_3 levels are seldom encountered.

Pesticides and Other Semivolatile Organics

Pesticides include a large group of commercially available toxic organic compounds used to control pests. Indoor sources of these substances include spray cans, pest strips and other coated surfaces, and contaminated fruits and flowers. Some of the pesticides commonly used in or near the indoor residential environment are chlordane, used to control carpenter ants and termites; dichlorvos, used in flea collars for dogs and cats; and carbamate, used in home insecticides. Limited data exist on indoor concentrations of pesticides.

Polychlorinated biphenyls (PCBs) have excellent dielectric properties for use in electric transformers and capacitors. PCBs are no longer used in indoor applications, but large office buildings sometimes have PCB-containing transformers and many homes still contain PCB-filled fluorescent light ballasts. Limited data exist on indoor PCB concentrations.

Polyaromatic Hydrocarbons and Other Organic Particulate Constituents

Polyaromatic hydrocarbons (PAHs) represent a large family of complex organic substances that include known and suspected carcinogens. Although benzo-a-pyrene (BaP) may not well represent PAH exposures, BaP has often been measured as a surrogate indicator. PAHs are derived from incomplete organic combustion in such processes as coke manufacture, asphalt production and use, and coal burning. Indoors, the principal sources of PAH are woodburning, smoking, and cooking. A combustion source emits PAHs in a vaporous form that quickly condenses on suspended aerosols.

Concentrations of these substances are in the nanogram-per-cubic-meter range; and a great deal of debate has focused on the amount of total PAH missed by sampling only condensed PAH. However, exposure to the vapor phase PAHs may not be as significant as PAHs condensed onto particulates. Data on indoor to outdoor concentration comparisons are not available.

Radon and Radon Progeny

Rn is a noble gas that has three naturally occurring radioactive isotopes (atomic masses of 219, 220, and 222) with half lives of 3.96 seconds, 55.6 seconds, and 3.82 days, respectively. Because of its longer half-life, ^{222}Rn and its associated progeny (^{210}Polonium, ^{214}Lead, ^{214}Bismuth, and ^{214}Polonium) are the principal sources of Rn exposure.

Rn is spontaneously released from radium-containing geological materials. The gas may diffuse through pore spaces of the material or be transported by water and eventually enter the indoor air space by bulk diffusion through foundation materials, diffusion through cracks, or entry through the water supply. Additionally, a building composed of radium-bearing material may itself be a source of Rn.

Rn progeny levels are related to radon concentrations,* and both are determined by competing mechanisms of production and removal. However, the progeny ions may be intercepted by indoor surfaces (plate out), as well as become attached to aerosols. Generally, between 50 and 95 percent of the progeny ions become attached to aerosols, some of which could leave indoors due to air exchange.

Outdoor levels of Rn are generally on the order of 10^{-1} nCi/m^3, corresponding to 10^{-3} to 10^{-4} WL. Average indoor levels are estimated to be on the order of a few nanocuries per cubic meter (10^{-3} to 10^{-2} WL). Extreme cases exceeding 50 nCi/m^3 (on the order of 10^{-1} WL) have been reported.

Sulfur Dioxide

Except for kerosene space heaters, indoor sources of SO_2 are rare. It has been postulated that sulfur in kerosene can result in indoor SO_2 concentrations. Like O_3, SO_2 also undergoes chemical transformation on indoor surfaces such as upholstery fabrics, draperies, and carpets, resulting in lower indoor concentrations. The half-life period for SO_2, however, is longer than for O_3. In the absence of indoor sources, indoor SO_2 concentrations in homes have been generally found to be lower than outdoor concentrations.

Volatile Organics

A long list of volatile organic vapor compounds are emitted indoors. These compounds are commonly found in many modern building and decorating materials and in a variety of consumer products. Principal indoor sources of these compounds include solvents, furnishings, and other consumer products such as aerosols and coatings. Various indoor activities such as cooking, smoking, and arts and crafts also generate emissions of volatile organics. Concentrations of these pollutants vary widely from home to home, depending on source, strength, rate of ventilation, and other factors. The expense of chemical analysis limits the measurement of indoor concentrations of volatile organics, but studies show that indoor concentrations exceed outdoor levels.

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* Rn concentrations are usually stated in nanocuries per cubic meter (nCi/m^3). A curie is defined as 3.7×10^{10} radioactive disintegrations per second. Rn progeny activity is usually expressed in terms of working level (WL). One working level corresponds to any combination of Rn progeny in a liter of air that ultimately emits 1.3×10^5 megaelectronvolts (MeV) of alpha particle energy. In the ideal case, 1 nCi/m^3 is equivalent to 0.01 WL. In realistic situations, this relationship may be as low as 1 nCi/m^3 per 0.005 WL, for two reasons: Progeny ions remain unattached or the ions attach to other surfaces and thus are not measured.

FACTORS THAT AFFECT INDOOR AIR QUALITY

Many factors acting alone or in combination can influence the indoor concentrations of a pollutant. For example, pollutants infiltrate from outdoors, indoor sources generate pollutants, indoor air exfiltrates, and decay or cleaning devices remove pollutants. Thus, indoor changes in pollutant mass, which govern indoor concentrations, can be expressed as

accumulation rate = rate of [input + generation - output - sink]

$$\frac{dx}{dt} = \frac{VdC_{in}}{dt} = \begin{array}{l}\text{rate of}\\ \text{change in}\\ \text{mass due to}\end{array} \left[\begin{pmatrix}\text{infiltration}\\ \text{of outdoor air}\end{pmatrix} + \begin{pmatrix}\text{generation}\\ \text{indoors}\end{pmatrix} - \begin{pmatrix}\text{exfiltration}\\ \text{of indoor air}\end{pmatrix} - \begin{pmatrix}\text{indoor removal}\\ \text{of pollutants}\end{pmatrix} \right] \tag{1}$$

where: V is the indoor volume
C_{in} is the indoor concentration.

The four terms in the right-hand side of the equation are discussed below.

Infiltration of Pollutants from Outdoors

The amount of pollutants that infiltrates indoors is a product of two factors: (1) volume rate of air exchange (νV, where ν is the air exchange rate measured in air changes per hour) between outdoor and indoors through the building envelope and (2) outdoor pollutant concentrations (C_{out}). Additionally, when outdoor air enters a structure, a certain fraction, f, may be deposited in the cracks and crevices in the building envelope resulting in a filtration or scrubbing effect. Thus, the infiltration of pollutants for outdoor air over a time period, dt, can be expressed as $(1 - f)\nu VC_{out}dt$.

Indoor Generation

A variety of indoor sources--appliances and materials--generate certain pollutants. When a source is constantly producing these contaminants for a time period, dt, the indoor generation could be expressed as Sdt, where S is the rate of indoor emission. Although, to a limited extent, quantitative values for S may be estimated through indoor studies, chamber studies yield more reliable information.

The expression for S is more complex when a time-varying source is considered. For example, a gas range may be turned on for limited periods some days and not at all on other days. When the burner is on, the gas flow rate is varied to suit cooking. Even more important is that the quantitative information on S for various indoor sources and pollutants, even when treated as a constant rate, is not often available. Additionally, a generation term to account for the indoor reentrainment of a contaminant such as particulate matter is difficult to quantify.

Exfiltration of Indoor Air

Exfiltration, like infiltration, is the product of volume rate of air exchange (νV) and the concentration of air (C_{exit}) leaving the structure. In cases where the indoor space can be assumed to be well mixed, C_{exit} will be the same as C_{in}. Thus, the exfiltration term can be expressed as $\nu VC_{in}dt$. A further discussion on mixing appears later in this section.

Indoor Pollutant Removal or Decay

Certain pollutants such as NO_2, O_3, and SO_2 decrease in concentration due to chemical decay or adsorption of the contaminants, particularly on indoor surfaces. The rate of decay can be expressed as λdt, which has been studied to a limited extent for such pollutants. Another sink for indoor pollutants is their removal through air cleaning devices. This term would be simpler to quantify, as it depends on the volume of air going through a cleaning device and the efficiency of the device. This removal term can be expressed as $qFC_{in}dt$ when q is the volume flow rate and F is the fraction removed by cleaning devices.

Generalized Mass Balance Equation

Considering the four terms in equation (1), a generalized mass balance equation for indoor concentration under well-mixed conditions would be

$$VdC_{in} = (1-f)\,\nu VC_{out}dt + Sdt - \nu VC_{in}dt - \lambda dt - qFC_{in}dt$$

or

$$\frac{dC_{in}}{dt} = (1-f)\nu C_{out} - \frac{S}{V} - \nu C_{in} - \frac{\lambda}{V} - \frac{qFC_{in}}{V} \tag{2}$$

To account for imperfect mixing of the interior, a mixing factor is introduced. The mixing factor, m, can be defined as the ratio of residence time of a pollutant under well-mixed conditions over actual residence time.

In other words, the air exchange rate for a pollutant is the product of m and the air exchange rate, or equal to mν. Thus, in the absence of ideal mixing conditions, the equation (2) can be modified to

$$\frac{dC_{in}}{dt} = (1-f)m\nu C_{out} - \frac{S}{V} - m\nu C_{in} - \frac{\lambda}{V} - \frac{qFC_{in}}{V} \qquad (3)$$

This differential equation can be solved if the form of the parameters on the right-hand side are known. The form of this time-dependency (or dependency on other variables) will vary for different pollutants and different situations. Thus, a general solution will be exceedingly complex. Illustrative solutions of this equation for two different conditions are given below.

Example

CO may be the simplest case to consider. CO does not decay (thus, $\lambda = 0$) and cannot be removed by available air cleaning devices ($F = 0$). It also does not get deposited during infiltration ($f = 0$). Further assume that outdoor concentration of CO is zero, the house is completely tight ($\nu = 0$), the circulation fan is on ($m = 1$), and a gas burner of the cooking range is on at the maximum setting. The emission rate for CO has been found to be 1800 mg/h (Traynor et al. 1979). If we assume an average single family residence of 1500 ft^2, the house volume (V) would be approximately 325 m^3.

Given this information, one can insert proper numerical values into equation (3):

$$\frac{dC_{in}}{dt} = (1-f)\cancelto{0}{m}\nu C_{out} + \frac{S}{V} - \cancelto{0}{m}\nu C_{in} - \cancelto{0}{\frac{\lambda}{V}} - \cancelto{0}{\frac{qFC_{in}}{V}} \qquad (4)$$

or,

$$\frac{dC_{in}}{dt} = \frac{S}{V} = 1800\left(\frac{mg}{h}\right) \times \frac{1}{325}\left(\frac{1}{m^3}\right) = 5.5\left(\frac{mg}{m^3} \times \frac{1}{h}\right) = 4.8\left(\frac{ppm}{h}\right) \qquad (5)$$

Thus, in such a case, the indoor concentration would increase at the rate of almost 5 ppm per hour. If we assume that the initial indoor concentration before turning on the burners was zero, at the end of 2 hours the indoor concentration will be 9.6 ppm.

Let us now make the same example somewhat more realistic by assuming an air exchange rate of one-half air changes per hour ($\nu = 0.5\ h^{-1}$). If we assume that C_{out} is 2 ppm and remains constant, initial indoor concentration (i.e., before starting the gas range) will be equal to outdoor concentration. With the forced air fan on providing good mixing ($m = 1$), equation (3) becomes

$$\frac{dC_{in}}{dt} = 1 \times 0.5\left(\frac{1}{h}\right) \times 2.3\left(\frac{mg}{m^3}\right) + 1800\left(\frac{mg}{h}\right) \times \frac{1}{325}\left(\frac{1}{m^3}\right)$$

$$- 1 \times 0.5\left(\frac{1}{h}\right) \times C_{in}\left(\frac{mg}{m^3}\right)$$

$$= (6.69 - 0.5\ C_{in})\left(\frac{mg}{m^3}\right) \times \left(\frac{1}{h}\right) \qquad (6)$$

Rearranging equation (6),

$$\frac{dC_{in}}{1 - 0.075\ C_{in}} = 6.69\ dt \qquad (7)$$

Solving the differential equation,

$$C_{in}\Big|_{C_{in,o}}^{C_{in,T}} = 13.3\ (1 - e^{-0.5\ t})\Big|_{o}^{T} \qquad (8)$$

Thus, to calculate C_{in} after 2 hours,

$$C_{in,2} = 13.3\left(1 - \frac{1}{e}\right) - C_{in,o}. \qquad (9)$$

But according to initial conditions, $C_{in,o} = 2.3\ mg/m^3$, thus,

$$C_{in,2\ h} = 5.3\ ppm. \qquad (10)$$

With an air exchange rate of only 0.5 air changes per hour, the indoor concentration does not increase as rapidly as it did for the earlier case with no air exchange.

REVIEW PUBLICATIONS

Several publications--books, journal articles, proceedings of symposia, and technical reports--describe different aspects of indoor air quality and related research. Below is an annotated bibliography of some of the important publications providing additional information.

National Research Council, Committee on Indoor Pollutants. 1981. Indoor Pollutants. National Academy Press, Washington, D.C.

The National Research Council (NRC) report, containing over 500 pages, is a comprehensive review and appraisal of indoor air quality literature. This report includes chapters on sources and characterization of indoor pollutants, factors that influence exposure, monitoring and modeling, health effects, welfare effects, and control of indoor pollution. Recommendations for further research are presented, and an extensive list of references follows each chapter. Although the NRC report lacks author or subject indexes, the report can serve as a starting point for any literature review.

Meyer, C.B. Indoor Air Quality. 1983. Addison-Wesley Publishing Co., Inc., Reading, Mass.

Intended for specialists as well as nonspecialists, Meyer's book provides a useful review of the chemical, physical, and biological parameters of indoor air quality. Opening chapters of the 434-page book provide an overview and trace the history of indoor air problems. Other chapters discuss comfort factors, building parameters, indoor pollutants and sources, monitoring techniques, indoor concentrations and exposure, health effects, control techniques, and regulatory trends. Summaries of results and data from various research studies are included. The hard-bound book is supplemented by an extensive bibliography that is current to March 1982. Author and subject indexes enhance the utility of the book.

Wadden, R.A., and P.A. Scheff. 1983. Indoor Air Pollution, Characterization, Prediction, and Control. John Wiley and Sons, Inc., Somerset, N.J.

Developed for an Air Pollution Control Association Continuing Education Course on indoor air pollution, this book provides a review of indoor air quality problems and offers methods for identification and amelioration. The text is organized into four areas: (1) characterization, including indoor sources, measurement techniques, and health effects criteria; (2) prediction, which summarizes indoor air quality models; (3) control, describing control systems standards and design; and (4) application, which addresses both commercial and domestic applications. (This textbook was unavailable for review at the time of publication.)

Environment International. 1982. Vol. B, Nos. 1-6, Special Issue: "Indoor Air Pollution." Pergamon Press, Elmsford, N.Y.

This special issue contains 67 articles selected through peer review from more than 100 papers presented at the International Symposium on Indoor Air Pollution, Health and Energy Conservation held at Amherst, Massachusetts, in 1981. The volume addresses five topics: (1) Policy and Public Health; (2) Sources, Concentrations, and Exposures to Pollutants (with specific attention to Rn, organics, HCHO, CO, and aerosols); (3) Health and Comfort Aspects of Indoor Pollutants and Indoor Climate; (4) Engineering Aspects of Ventilation, Contaminant Control, and Energy Conservation; and (5) Modeling the Physical and Chemical Behavior of Pollutants Within Structures.

Building Air Change Rate and Infiltration Measurement. 1980. C.M. Hunt, J.D. King, and H.R. Trechsel, eds. ASTM Special Technical Publication 719, American Society for Testing and Materials, Philadelphia, Pa.

This volume contains papers presented at a symposium held on March 13, 1978, in Washington, D.C., and organized by the ASTM subcommittee E06.41 on infiltration performance. Eleven papers cover two major areas--measurement aspects of infiltration and significance of air infiltration on such factors as energy consumption, building design and codes, and indoor air pollution. The volume also contains a transcript of the panel discussion and a symposium summary.

Yocom, J.E. 1982. "Indoor-Outdoor Air Quality Relationships." J. Air Pollut. Control Assoc. 32(5):500-20. See also, Discussion Papers, J. Air Pollut. Control Assoc. 32(9):904, September 1982.

The article reviews research conducted on the relationships of indoor and outdoor air quality. The Air Pollution Control Association (APCA) commissioned the article as a critical review paper, and it was presented and critiqued at the APCA meeting in New Orleans in June 1982. The article begins with a historical overview, followed by a review of research on a pollutant-by-pollutant basis. The conclusions consist of generalized ratios of indoor to outdoor concentrations for each pollutant. Although these generalized ratios can be useful, various discussion papers point out the limitations of such an approach.

Wallace, L.A., and W.R. Ott. 1982. "Personal Monitors: A State-of-the-Art Survey." J. Air Pollut. Control Assoc. 32(6):601-10.

The progress in personal monitoring is reviewed in this article. It defines types of personal monitors and sampling approaches, reviews their history, and discusses the current status on a pollutant-by-pollutant basis. The article is especially useful because it characterizes instruments in terms of "field-tested" and "laboratory-tested" equipment. In addition, the article defines the research needed to further develop personal monitors.

Meyer, C.B., and R.P. Hartley. 1982. Inventory of Current Indoor Air Quality Related Research. EPA-600/57-81-119, NTIS PB 82-127-952, National Technical Information Service, Springfield, Va.

This bibliography, prepared in 1981, lists a total of 171 current or recent projects covering six areas of indoor air quality research: monitoring, instrumentation, health effects, control technology, risk assessment, and pollutant characterization. The bibliography cross-references the following subjects: Rn, nitrogen oxides, CO, HCHO, asbestos, RSP, organics, tobacco smoke, odors, O_3, biological pollutants, and multipollutant studies. Information on each project includes principal investigator, project sponsor, funding level, and abstract.

Sandia National Laboratories. 1982. Indoor Air Quality Handbook for Designers, Builders, and Users of Energy-Efficient Residences. Sandia 82-1773, Albuquerque, N. Mex.

The purpose of this handbook is to assist designers, builders, and users of energy-efficient residences in achieving the apparently conflicting goals of energy efficiency and good indoor air quality. In an easy-to-understand style, the handbook covers a variety of topics including effects of building systems, health effects, evaluation, control, and legal aspects.

REFERENCE

Traynor, G. 1979. "Gas Stove Emissions." Presented at the Annual Technical Review on Building Ventilation and Indoor Air Quality, Lawrence Berkeley Laboratory, Berkeley, Calif., October 30-31.

SECTION 4

MEASUREMENT SYSTEMS

Many measurement instruments and methods developed for outdoor ambient and workplace monitoring have been adapted to indoor settings, but relatively few instruments and analytical methods have been developed specifically for indoor monitoring. Two types of measurement systems can be used for indoor monitoring. The first consists of purchasing off-the-shelf, commercially available instrumentation, and the second requires assembling commercially available components.

The use of commercially available instrumentation offers obvious benefits: The measurement techniques are accepted, and the user avoids the time or effort needed to assemble and test measurement systems. For some applications, however, commercial instrumentation is unavailable or too expensive. In some of these cases, users can assemble a measurement system by using commercially available components.

This document defines an "instrument" as a ready-to-use measuring device, such as a GE carbon monoxide detector, that can be purchased preassembled. In contrast, a "method" indicates that the user must assemble various components, possibly from different suppliers, to construct a system by using a standard or an accepted method. Sampling for organic vapors, for example, may be carried out by a number of methods, all of which involve a user-fabricated sorbant trap for sample collection followed by gas chromatography associated with various detention systems such as mass spectroscopy, electron capture, or flame ionization.

This section addresses both measurement systems. A categorization scheme is defined. Operating principles of various measurement systems are outlined and measurement systems currently available are listed. Finally, sources of information and key references for instrumentation and methods are given. The background provided in this section, combined with the design considerations described in the next section, will enable users to select the appropriate measurement systems.

DEFINITIONS

In selecting instrumentation or methods, users must consider the monitoring objectives. The following questions will help to define the monitoring objectives:

- Is recording the peak concentration of a pollutant important to the study? Will short-term (from a few hours to 1 day) time-weighted averages suffice? Or are long-term averages (many days, weeks, or months) needed?

- Will the exposure characterization measurement be conducted for a fixed location or for individuals who may move from one microenvironment to another?

To translate these objectives into instrument or method categories, users can consider three factors. First is sampling mobility, followed by operating characteristics and, finally, output characteristics. The instruments and methods in use provide three classes of sampling mobility:

- Personal--The unit may be conveniently carried or worn by a person.
- Portable--The unit may be hand-carried from one place to another during sampling, but the unit does not offer the convenience of a personal device.
- Stationary--The unit must operate from a fixed location.

Obviously, either a personal or portable measurement system can be used in a stationary mode. Portable instruments or methods are often the only recourse for personal monitoring of some pollutants, and such instruments are less expensive than the equivalent stationary instruments.

Within each class of mobility are two categories of operating characteristics:

- Active--A power source is required to draw sample air to a sensor or collector.
- Passive--No power source is required; sample acquisition relies on diffusion.

Finally, within each mobility and operating class, users must define the needed output characteristics of the measurement system:

- Analyzer--Almost simultaneously, the unit produces a signal that corresponds to the pollutant concentration.
- Collector--The collected sample is analyzed, or quantitated, in a laboratory.

Analyzers are most useful in determining peak concentrations. Additionally, because the analyzer produces time series information, the integrated results can generate time-weighted average concentrations. Data obtained from collectors are limited only to time-weighted average concentrations; information on peak concentrations is not available.

This classification system produces 12 combinations of categories, ranging from simple stationary/passive/collectors to sophisticated personal/active/analyzers.

INSTRUMENTS AND METHODS

The measurement parameters of greatest interest in indoor air quality monitoring are pollutant concentrations, air exchange rates, and environmental variables. The paragraphs below summarize the technologies associated with these measurements. Appendix A describes the instruments, and Appendix B discusses the various methods that use components.

Pollutant Concentrations

Pollutants of interest in indoor air quality monitoring include CO, NO_2, SO_2, O_3, HCHO, and Rn and Rn progeny. Other pollutants of interest may be considered as classes of pollutants with variable compositions: fibrous aerosols (of which asbestos is of great concern), biological aerosols, a number of organic vapors (including pesticides), and IP. Table 3 shows a number of measurement techniques available for the above pollutants.

Table 4 highlights the operating principles of selected pollutant measurement systems. For each pollutant and operating principle, the categories of instruments or methods are listed. The table also cross-references parts of Appendixes A and B. For CO, NO_2, SO_2, and O_3, stationary analyzers have been developed to support the monitoring required by the NAAQS. Instruments that appear on the EPA List of Reference and Equivalent Methods for these pollutants are listed in Appendix A. In some cases, portable analyzers based on reference and equivalent methods are available.

Recent advances in electrochemical oxidation cells and supporting electronics have produced personal and portable analyzers for CO and SO_2. Signal integrating and data logging devices, which can be used for integration over time of continuous readings for personal monitors, are available (Appendix A). While such devices have been extensively used with CO personal monitors, they can be used with any device providing a continuous analog voltage signal. Passive collectors are available for NO_2 and SO_2.

Commercially available devices for monitoring HCHO include an automated wet chemical analyzer and two passive collectors. For fibrous aerosols, especially asbestos, users can determine concentrations with manual methods or with a portable analyzer.

Portable IP analyzers are based on optical scattering and on piezoelectric resonance. One manufacturer offers an optical-scattering analyzer sufficiently miniaturized for personal monitoring of IP. Stationary collectors are also available. Appendix B discusses methods for collecting IP for personal exposure and for analyzing organic and inorganic constituents.

Table 3. TYPES OF AVAILABLE MEASUREMENT SYSTEM CATEGORIES BY POLLUTANT*

		Personal		Portable		Stationary	
		Active	Passive	Active	Passive	Active	Passive
Asbestos and other Fibrous Aerosols	Collector	▨				▨	
	Analyzer			▩			
Biological Aerosols	Collector					▩	
	Analyzer						
Carbon Monoxide	Collector						
	Analyzer	▩	▩	▩		▩	
Formaldehyde	Collector		░				
	Analyzer			░			
Inhalable Particulates	Collector	▩				░	
	Analyzer		▩			▩	
Metals and Other Inorganic* Particulate Constituents	Collector	▨		▨		▨	
	Analyzer						
Nitrogen Dioxide	Collector		▩				
	Analyzer			▩		▩	
Ozone	Collector						
	Analyzer			▩		▩	
Pesticides and Other Semivolatile Organics	Collector	▨		▨		▨	
	Analyzer						
Polynuclear Aromatic Hydrocarbons & Other Organic Particulate Constituents*	Collector	▨		▨		▨	
	Analyzer						
Radon and Radon Progeny	Collector					░	▩
	Analyzer			▩		▩	
Sulfur Dioxide	Collector						
	Analyzer	▩				▩	
Volatile Organics	Collector	▨		▨		▨	
	Analyzer						

* Organic/inorganic collection is similar to that for IP; methods discussed in Appendix B cover analytical techniques.

LEGEND:

▩ One or more commercially available instruments for this pollutant and measurement category are summarized in Appendix A.

▨ One or more methods for this pollutant and measurement category are summarized in Appendix B.

░ Instruments as well as methods are summarized in Appendixes A and B.

TABLE 4. SUMMARY OF SELECTED POLLUTANT CONCENTRATION MEASUREMENT SYSTEMS

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Asbestos and other fibrous aerosols	Induced Oscillation/Optical Scattering--Sample air passes through an oscillating electric field. Fibers are detected by detecting right-angle scattering pulses from larger illumination aligned with the fiber axis.	Portable	Active	Analyzer	A1-1
	Filtration--A laboratory analyzes the filters.	Personal	Active	Collector	B
Biologic aerosols	Impaction--Sample air passes through a series of selective stages (petri dish containing agar); inertial effects cause particles in size ranges of interest to collide with collector surface. Microbial colonies are incubated for 24 hours and counted manually.	Stationary	Active	Collector	A2-1, A2-2
Carbon monoxide	Nondispersive Infrared (NDIR)--Infrared radiation passes through parallel optical cells, one containing sample air, the other containing reference CO-free air. The difference in absorbance relates to CO concentration.	Stationary	Active	Analyzer	EPA Reference Method, Appendix A
	Gas Filter Correlation (GFC)--Infrared radiation passes through a spinning filter wheel that contains a sealed CO reference cell and a nitrogen reference cell. The IR beam then passes through a chamber containing sample air and is detected. The signal difference observed between the nitrogen cell and the CO cell relates to CO concentration.	Stationary	Active	Analyzer	EPA Equivalent Method, Appendix A
	Electrochemical Oxidation--Sample air passes into an electrochemical cell where oxidation of CO to CO_2 produces a signal related to the CO concentration.	Personal Personal Portable	Active Passive Active	Analyzer Analyzer Analyzer	A3-3 A3-2, A3-5 A3-1, A3-4
Formaldehyde	Wet Chemical--HCHO is scrubbed from the sample airstream by a standard reagent solution. Addition of a second reagent forms a distinctive color whose intensity is related to HCHO concentration.	Portable	Active	Analyzer	A4-4 and B
	Sorption/Spectrophotometry--HCHO is adsorbed onto treated substrate and subsequently desorbed and quantitated in the laboratory.	Personal	Passive	Collector	A4-1, A4-2, A4-3, B

* A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.

(continued)

TABLE 4. (continued)

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Inhalable particulate matter	Optical Scattering--Sample air passes through a size-selective inlet prior to entering an optical cell. Forward light scattering from controlled light source relates to IP concentration.	Personal Portable	Passive Active	Analyzer Analyzer	A5-1 A5-2
	Filtration--Sample air passes through a size-selective inlet. Particles in size range(s) of interest are retained on filter(s) for mass determination in laboratory.	Stationary	Active	Collector	A5-3, A5-4, B
	Impaction--Sample air passes through a series of selective stages; inertial effects cause particles in size range of interest to collide with collector surface.	Personal	Active	Collector	A5-5
	Piezoelectric Resonance--Sample air passes through a size-selective inlet. Particles within the size range of interest are electrostatically precipitated onto a quartz crystal. Alterations in oscillation frequency relate to collected mass.	Portable Stationary	Active Active	Analyzer Analyzer	A5-6 A5-6
Metals and other inorganic particulate constituents	Filter Collection/Laboratory Analysis--Inorganic constituents are collected by passing sample air through a suitable filter. Metals may be quantitated by atomic absorption spectroscopy, neutron activation analysis, proton-induced X-ray fluorescence. Nitrates and sulfates can be determined spectrophotometrically.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B
Nitrogen dioxide	Gas-Phase Chemiluminescence--Photon emission that accompanies reaction of NO with O_3 is monitored to simultaneously quantify NO and NO_x. NO_x is quantified by first reducing all oxides of nitrogen to nitric oxide, NO. NO_2 is the algebraic difference between NO_x and NO.	Stationary Portable	Active Active	Analyzer Analyzer	EPA Reference Method, Appendix A A6-1
	Triethanol Amine (TEA) Adsorption--NO_2 is quantitatively sorbed onto treated substrate for subsequent quantitation in the laboratory.	Personal	Passive	Collector	A6-3, A6-5
	Wet Chemical--NO_2 reacts with a reagent system and is quantified colorimetrically.	Portable Personal	Active Passive	Analyzer Collector	A6-4 A6-2

* A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.

(continued)

TABLE 4. (continued)

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Ozone	Gas-Phase Chemiluminescence--Photometric detection of the chemiluminescence resulting from the gas-phase reaction between ethylene and O_3.	Stationary Portable	Active Active	Analyzer Analyzer	EPA Reference Method, Appendix A A7-1
	Gas-Solid Phase Chemiluminescence--Photometric detection of the chemiluminescence resulting from the reaction between O_3 and rhodamine-B.	Stationary	Active	Analyzer	EPA Equivalent Method, Appendix A
	Ultraviolet Absorption--Measurement of the difference in ultraviolet intensity between sample air and reference.	Stationary	Active	Analyzer	EPA Equivalent Method, Appendix A
Pesticides and other semivolatile organics	Sorbant Collection/Laboratory Analysis--Semivolatile organics are collected by passing sample air through polyurethane foam. In the laboratory, compounds are extracted for chromatographic quantitation.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B
Polyaromatic hydrocarbons and other organic particulate constituents	Filter Collection/Laboratory Analysis--Organic constituents are collected by passing sample air through a suitable filter. Organic constituent may be quantified through a number of chromatographic techniques.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B
Radon/ radon progeny	Filtration/Gross Alpha Counting--Rn progeny collect onto a filter; consequent alpha activity relates to working level.	Stationary	Active	Collector	A8-2
	Electrostatic Collection/Thermoluminescent Dosimetry--Rn passes into a special chamber where subsequent progeny (ions) are electrostatically focused onto a thermoluminescent dosimeter (TLD) chip. Subsequent alpha disintegrations create metastable defects in the TLD, which is deactivated and quantified in the laboratory.	Stationary	Passive	Collector	A8-1, A8-6
	Grab Sample/Alpha Scintillation--Rn progeny collect in a filter; Rn is collected in a scintillation flask. Subsequent alpha activity relates to working level (filter sample) and to Rn concentration (scintillation flask).	Portable	Active	Analyzer	A8-3

* A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.

(continued)

TABLE 4. (concluded)

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Radon/ radon progeny (continued)	Filtration/Alpha Spectroscopy Coupled to Electrostatic Collection/Alpha Spectroscopy--Rn progeny (ions) are collected on a filter; subsequent alpha decay relates to working level. Rn passes into a special chamber where subsequent decay ions are electrostatically focused onto a detector; subsequent alpha decay relates to Rn concentration.	Stationary	Active	Analyzer	A8-4
	Filtration/Alpha and Beta Spectroscopy--Rn progeny are collected on a filter; subsequent alpha and beta activity relate to working level.	Stationary	Active	Analyzer	A8-5, A8-7
	TRACK ETCH™--Alpha-sensitive film registers damage tracks when chemically etched; average Rn concentration is related to the number of damage tracks per unit area.	Stationary	Passive	Collector	A8-8
	Sorption/Gamma Activity--Rn is adsorbed onto activated charcoal; subsequent gamma activity is related to average Rn concentration.	Stationary	Active	Collector	B
Sulfur dioxide	Flame Photometric Detection (FPD)--Measurement of sulfur-specific emissions from hydrogen-rich air flame.	Stationary	Active	Analyzer	EPA Equivalent Method
	Pulsed Fluorescence--Measurement of the intensity of the ultraviolet fluorescence of SO_2 excited by a high-intensity light source.	Stationary	Active	Analyzer	EPA Equivalent Method
	Wet Chemical--SO_2 reacts with a reagent system and is quantified conductometrically or colorimetrically.	Stationary Portable	Active Active	Analyzer Analyzer	EPA Equivalent Method A9-3
	Electrochemical Oxidation--Sample air passes into an electrochemical cell where oxidation of SO_2 produces a signal proportioned to concentration.	Personal Personal	Active Passive	Analyzer Analyzer	A9-1 A9-2
Volatile organics	Sorbant Collection/Laboratory Analysis--Volatile organics are collected by passing sample air through a suitable absorbant column. In the laboratory, compounds of interest are desorbed for chromatographic quantitation.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B

* A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.

For Rn and Rn progeny, a variety of sophisticated monitors are available. Many are small enough to be considered portable, but the measurement techniques are most often geared to stationary measurements. Two types of passive Rn collectors are available--the TRACK ETCH™ radon detector and two thermoluminescent dosimeters. In addition, a recently developed passive collection method relies on adsorption onto charcoal.

As a class, organic vapors involve hundreds of chemicals, including pesticides, and many methods of analysis. Appendix B describes some common broad-spectrum collection methods.

Methods for collecting and analyzing biological aerosols are discussed in specialized references such as the following:

- Gregory, P.H. 1973. Microbiology of the Atmosphere. 2d ed. John Wiley and Sons, New York, N.Y.

Air Exchange Rates

The continual transfer of air across the building envelope is an important determinant for indoor pollutant levels. Air exchange results from one of the following:

- Infiltration--the uncontrollable leakage of air through cracks, joints, and pore spaces in the building envelope
- Natural Ventilation--deliberately augmented air exchange through the opening of doors, windows, and vents
- Mechanical Ventilation--deliberately augmented air exchange through the use of fans.

In the absence of natural or mechanical ventilation, the rate of air infiltration is dependent on many factors such as type of structure, wind velocity, orientation of the structure, and indoor-outdoor temperature differences.

The quantification of air exchange rates generally relies on indirect measurements. General methods, described in Appendix B, include fan pressurization, tracer gas dilution, and measurement of cracks. Fan Pressurization and Tracer Gas Dilution have been designated as standard practice by the ASTM for evaluating infiltration rates on a single test basis. The passive method using the tracer gas dilution technique is also available. The ASHRAE crack method relies upon measurement of the lengths of cracks, such as those around windows and doors, for calculation of air exchange.

Users can measure air flow through mechanical ventilation systems with a variety of instruments and methods including visual tracers (i.e., smoke releases), anemometers, and pitot tubes. Appendixes A and B do not discuss this topic, but detailed procedures and instrument descriptions appear in the following publications:

American Conference of Governmental Industrial Hygienists. 1980. Industrial Ventilation. 16th ed. Committee on Industrial Ventilation, Lansing, Mich.

American Society of Heating, Refrigeration and Air-Conditioning Engineers. 1980. ASHRAE Handbook--1977 Fundamentals. New York, N.Y.

Environmental Quantities

Important environmental quantities in indoor air quality monitoring are air temperature, humidity, wind speed and direction, solar radiation, and barometric pressure. Users can locate dealers for the required measuring devices through the catalogs and resource directories identified in the next subsection.

KEY REFERENCES AND OTHER INFORMATION SOURCES

References and information sources for instruments and methods include scientific literature describing fundamental technologies, catalogs and directories describing products, and manufacturers' literature on individual products. Recognized sources of information in the scientific literature include the following:

- Air Pollution. 1976. 3rd ed., Vol. III, "Measuring, Monitoring and Surveillance of Air Pollution." A.C. Stern, ed. Academic Press, New York, N.Y.
- American Conference of Governmental Industrial Hygienists. 1976. Air Sampling Instruments for Evaluation of Atmospheric Contaminants. 5th ed. Cincinnati, Ohio.
- Linch, A.L. 1981. Evaluation of Ambient Air Quality by Personal Monitoring, Vol. I: "Gases and Vapors," and Vol. II: "Aerosols, Monitor Pumps, Calibration, and Quality Control." CRC Press, Inc., Boca Raton, Fla.
- Lawrence Berkeley Laboratory, Environmental Instrumentation Groups. Instrumentation for Environmental Monitoring. University of California, Berkeley, Ca. (1st ed. in 1972, with periodic updates).

- American Public Health Association. 1977. Methods of Air Sampling and Analysis. 2d. ed. M. Katz, ed. Washington, D.C.

Especially useful are the professional journals that periodically offer reviews and information on recent developments. The Journal of the Air Pollution Control Association, the American Industrial Hygiene Association Journal, and Analytical Chemistry are examples. These journals often refer to additional literature on instruments and methods.

Examples of consolidated catalogs include Pollution Equipment News, published seven times a year, and Industrial Hygiene News, published six times a year. Reinbach Publication of Pittsburgh, Pennsylvania, circulates both without charge to qualified subscribers. Each catalog continually updates a number of product lines, and an annual buyer's guide cross-references manufacturers by their products. Some professional societies also publish annual directories listing instrument manufacturers by their products. Examples include the Directory and Resource Book from the Air Pollution Control Association and the Guide to Scientific Instruments from the American Association for the Advancement of Science.

Finally, many instrument manufacturers publish technical notes covering instrument operation, special applications, and other information. Many references cited for individual instrument summaries in Appendix A include such manufacturers' notes.

SECTION 5

DESIGN CONSIDERATIONS

When designing a monitoring program, the user must consider objectives, available technology, and resources. An examination of objectives is especially important if the collected monitoring data are to fulfill the needs of the program. Indoor air quality monitoring programs typically fall under either of two broad categories of study objectives:

1. To support applied research

2. To investigate problems associated with specific buildings.

Examples of objectives in the first category include comparing indoor and outdoor pollutant levels, evaluating the impact of indoor source emissions, and determining changes caused by weatherization. The second category of studies often occurs when occupants of a building complain of illnesses or perceived health effects they associate with problems in indoor air quality.

The two categories of studies are entirely different, at least in terms of approach. For the first category of studies, the current base of knowledge permits the user to postulate the contaminants to be monitored. If, as an example, an evaluation is needed of the impact of weatherization, monitoring is considered for combustion gases, radon, and formaldehyde. If a study is aimed at source characterization, the selection of contaminants for monitoring will be even more straightforward, because most of the source emissions are known.

In contrast, the determination of which contaminants will be monitored is an important part of an investigation of building-associated air quality problems. In an extreme case, the identification of problem contaminants completes the investigation, and no monitoring program may be required.

This section presents some preliminary considerations for those who investigate building-associated air quality problems. In addition, a methodological sequence useful in designing monitoring programs is described. This methodology is based on the results of past research, the current state of knowledge, factors that affect indoor air quality, and available technology for measurement systems. Because available resources are an important consideration, this section points out the need to consider resources at different stages in the design development. Some considerations for selecting the location of monitoring probes are discussed, and examples of design development are listed.

DESIGN CONSIDERATIONS FOR INVESTIGATING BUILDING-ASSOCIATED PROBLEMS

The investigation of building-associated problems often begins as a result of reported illnesses, symptoms, or complaints about air quality. In such cases, the immediate reaction is to conduct monitoring to identify the causes or the contaminants responsible for health-related or air quality problems. Yet experience shows that such a monitoring approach is seldom useful. The following points contribute to inconclusive investigations:

- Complaints by nature are subjective; hence, to sort out the useful information from possibly emotionally charged reports demands a systematic approach.
- Multiple etiologic factors, environmental factors, and even psychological factors may be responsible for complaints. Contaminants, if present, may be low-level and difficult to identify and to relate to health effects.

Thus, seemingly straightforward investigations of building-associated problems become complex problems involving both people and their indoor environments. An emphasis on either problem area will likely prove less than productive.

The best approach in addressing such problems is to keenly observe and gather facts related to both the physical environment and people. In a practical sense, this is the approach used by detectives who carefully evaluate all factors that can provide a solution to the problem. The relevant factors to be examined may include the following:

- Building ventilation and air exchange
- Indoor sources and other physical factors
- Complaints
- Complainants.

A systematic evaluation of observations and facts will narrow the many potential causes and help to pinpoint the problem.

The first stage of the evaluation should include these steps:

- Examine complaints for validity, consistency, and diagnosis
- Evaluate the location of complaints to help determine the origin and source
- Collect information from persons with health complaints and compare descriptions with those who are unaffected

- Survey and evaluate ventilation systems including the location of exhausts with respect to intakes

- Survey unusual indoor sources or other physical factors and immediate outdoor environment that may cause the injection of contaminants into the indoor environment.

In general, no extensive measurements should be conducted, although measurements of ventilation rates and ventilation-related parameters such as carbon dioxide may be appropriate in evaluating the ventilation system.

The results of these steps will narrow the scope of the investigation. Once the possibilities are narrowed, the investigator can proceed in one of two ways: (1) use the collected information to alter possible conditions related to the problem through a trial-and-error approach or (2) continue the investigation and include the use of monitoring programs to pinpoint the causes. No further definitive guidelines can be given, as the state of the art in building-associated problems is not fully developed. For more information, however, investigators are encouraged to review a paper by Kreiss (1983).

METHODOLOGY FOR THE DEVELOPMENT OF MONITORING

Figure 2 depicts the conceptual approach to developing a monitoring design. Although the figure shows nine steps, users may vary the order of consideration or otherwise adapt the important design elements and their relationships to their needs.

Steps 1 through 4 in Figure 2 represent the design preparation stage. Step 1 consists of selecting a preliminary list of pollutants to be measured. Steps 2 and 3 are exploratory steps for reviewing available instrumentation and developing broad options for sample sizes and location(s). Various factors that can influence the parameters used in equation (3) (Section 3) are examined in Step 4, so that an initial design can be developed. This design, as well as information from any previous studies, can assist in establishing the sample size in Step 5. Based on the results of previous steps, a preliminary decision can be made on selecting types of instrumentation in Step 6. In Step 7, cost estimates should be prepared and compared with potential or available resources.

Often preliminary estimates will exceed available resources; in such cases, selection of pollutants, type and sophistication of instrumentation, and sample size should be reconsidered. This feedback loop, shown in Step 8, can be repeated to align more closely the cost estimates and the available resources.

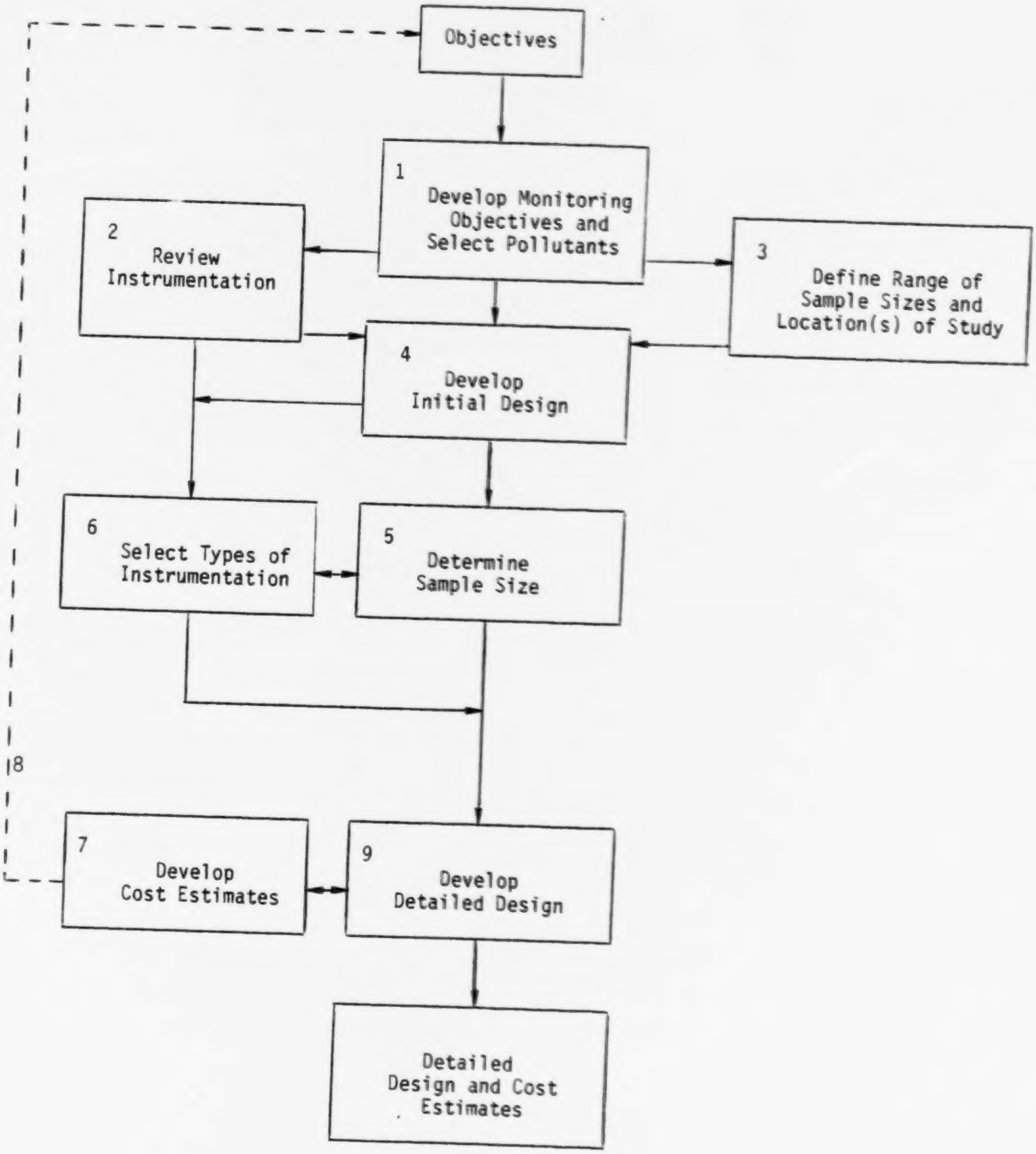
Objectives
1
Develop Monitoring Objectives and Select Pollutants
2
Review Instrumentation
3
Define Range of Sample Sizes and Location(s) of Study
4
Develop Initial Design
5
Determine Sample Size
6
Select Types of Instrumentation
7
Develop Cost Estimates
8
9
Develop Detailed Design
Detailed Design and Cost Estimates

Figure 2. Schematic flow chart for development of design.

It should be re-emphasized that Figure 2 presents only a conceptual approach, and some steps may be unnecessary in some applications. In certain situations, some steps may require little effort, while others may require significant effort beyond that described through page 54. Following are examples of steps that may require varying amounts of effort:

- Steps involving a range of sample sizes and locations may be based, at one extreme, on predefined objectives. At the opposite extreme, these steps may require considerable effort.
- Although the figure shows only one feedback loop, feedback for both technical and cost considerations may be needed at many points in development of the design.
- For a study with limited scope and resources, steps such as those to update the review of available instrumentation and methods may not be undertaken.

A brief discussion of each step depicted in Figure 2 follows.

Develop Monitoring Objectives and Select Pollutants

The objectives of a study generally help define the pollutants to be monitored. Developing a clear statement of monitoring objectives is a critical step in the design process because the objectives define both the motivation and the goals of subsequent monitoring activities. At first glance, this step seems trivial because most study problems can be considered synonymous with objectives. However, the operative term here is the word develop. This involves a systematic interrogation of the problem setting, the problem background, and the knowledge base needed to form both qualitative and quantitative goals that are as specific as possible.

Some typical objectives are as follows:

1. To quantify relationships between indoor and outdoor air quality
2. To determine the proportion of total exposure that is attributable to indoor exposure
3. To assess the effect of weatherization on indoor air quality
4. To determine the causes of indoor air quality problems in residences or other buildings.

For objectives 1 and 2, the study usually specifies the pollutants to be monitored. For example, a study with the first objective could consist of quantifying the relationship between indoor and outdoor levels of particulates. An example of objective 2 might be determining the extent of the nitrogen oxide total exposure that is attributable to indoor residential exposure.

The long list of pollutants for study objective 3 includes radon and formaldehyde, which have predominantly indoor sources and rate high on a list of pollutants considered for monitoring. Similarly, pollutants such as carbon monoxide, nitrogen oxides, and particulates are present outdoors, but they can also have significant indoor sources. Therefore, these two should also be considered. Volatile organics generated by the use of consumer products, along with many other pollutants or pollutant groups, could also be included.

Pollutants relating to objective 4 are not as obvious as those in the three previous cases. As described earlier, this type of study is aimed at isolating causes and controlling indoor air quality problems in residences or in other buildings, and a systematic approach outlined under "Design Considerations for Investigating Building-Associated Problems" should be used before the pollutants can be selected for monitoring.

Review Instrumentation

For each pollutant under consideration, various aspects of available measurement systems need to be reviewed. A wide variety of available instruments and methods with varying degrees of sophistication and associated costs are reviewed in Section 4 and in Appendixes A and B.

New instrumentation--especially personal and portable devices--is constantly being developed, tested, and marketed. Thus, the summary of available instrumentation and methods contained in this document, which was prepared in late 1982, must be updated before users begin any major design effort. Reference sources for an expanded search are listed in Section 4.

Define Range of Sample Size and Geographic Locations

An evaluation of the approximate range of sample sizes early in the design plan can be useful in selecting instrumentation and in determining the approximate extent of monitoring required. Note that the emphasis here is on range of sample sizes, not the actual sample size.

The range is dependent on objectives. For example, if the user envisions a study to develop models for seasonal, time-varying concentrations of various pollutants and energy-use patterns, then the number of houses can be very limited--even as few as one or two. This approach will permit extensive measurements of various pollutant concentrations and air exchange rates as inputs to model formulation and testing. For this type of study, fixed instruments with active analytical devices are the most suitable.

The opposite extreme is a study that investigates the effects of weatherization in a large number of houses. For a representative sample of several hundred houses, less expensive passive instruments might be used if the monitoring period is sufficiently long (e.g., 1 week or more). However, the concentrations obtained with passive monitoring will be averaged over the duration of the monitoring period, with no identification of short-term peaks.

Also to be considered under the range of sample sizes are the location(s) of the study and the type(s) of indoor environments addressed. Often the location may be stated in the objectives (e.g., assessment of the impact of weatherization on indoor air quality in residences in the Pacific Northwest). But in some cases, the study allows flexibility in the selection of appropriate location(s). Heating and cooling degree days, outdoor pollution levels, and urban-versus-rural settings are among the factors that must be considered in selecting geographic locations.

Develop Initial Design

The output from Steps 1, 2, and 3 will produce a list of probable pollutants to be monitored, the available instrumentation, and the approximate number and location(s) of structures to be considered. This list will serve as a starting point for developing an initial design, which requires consideration of three major areas: (1) selection of monitoring parameters, (2) frequency and duration of monitoring, and (3) monitoring location and probe placement. Examples of questions relating to design development in these three areas are as follows:

- What other parameters (in addition to selected pollutants) should be selected for monitoring?
- Over what period of time is the measurement for each parameter to be taken?
- Will monitoring take place throughout the year or only during selected seasons?
- Will monitoring occur on all days of the week or only on selected days?
- Can average exposure be monitored through passive techniques or must peak exposures be measured?
- If passive monitoring is inadequate, will intermittent monitoring be sufficient, or is continuous monitoring required for meeting objectives?
- How many monitoring locations per parameter and per structure are required?

- Where should the probes be placed?
- Will measurements for different parameters be completely independent, or will they parallel one another in some systematic way?

In selecting other parameters for measurement, users should examine the mass balance equation in Section 3 for each pollutant under consideration. The parameters that determine indoor concentrations of pollutants are C_{out} (i.e., outdoor concentration), ν (air exchange rate), and V (volume of the structure). These parameters, in addition to indoor concentrations, can be measured directly. The S (source generation rate), the λ (removal and decay rate), the f (filtration factor), and the m (mixing factors) either cannot be measured directly or require special experimental provisions, such as chamber studies for S and λ. These four can be quantified through modeling if sufficient data exist on parameters that can be monitored directly.

Monitoring frequency, duration, and location are partially dictated by study objectives and instrumentation preferences. For example, a study of the effects of weatherization on particulate levels during wood stove operation will focus on the winter season. Passive monitoring studies will require a sufficient monitoring time to ensure that minimum detection levels are exceeded. Studies of the effect of traffic patterns on residential CO levels might be restricted to selected hours of the day. A comparison of concentrations from two experimental homes--one tightened and the other not tightened--will benefit from parallel measurements.

An additional consideration is the manner in which the initial design meets the sample size requirement. The requirements may be met in two ways. One is by selecting many units (e.g., houses) and sampling each one for short periods of time (e.g., 1 day or 1 week), and the other is by selecting only a few units and sampling each for longer periods (e.g., 1 season or 1 year). These two approaches are not usually equivalent. In experimental situations, the latter option often must be pursued. Otherwise, some compromise between the two extremes may be preferred. As logistic considerations impact upon this decision, sample size may not be finalized until the detailed design is developed.

Determine Sample Size

In making the final determination of sample size, the preliminary selection of equipment and previously estimated range of sample size will serve as useful starting points. In addition to specific objectives of the monitoring design, the sample size (i.e., the total number of air samples) will depend on the following types of factors:

- Pollutant(s) to be monitored
- Nature of structure(s) to be monitored

- Area(s) of the country where monitoring is to take place
- Season(s) of the year during which monitoring is to take place
- Day(s) of the week on which monitoring is to take place
- Length of the time interval during which each sample is taken (e.g., grab sample, 1-hour sample, 24-hour sample).

Estimates from previous studies of the average pollution levels and variation around this average will be helpful in making sample size estimates. For the formulas presented below, preliminary estimates of the arithmetic mean, $\overline{X}$, and standard deviation, S, are required. The sampling conditions such as pollutant, structure type, and measurement interval for previous studies on which preliminary estimates are based should parallel as closely as possible the conditions surrounding the contemplated monitoring program. Unfortunately, in many instances there will be little or no information from previous studies. In these cases, one will have to make some assumptions or use best judgment as to expected levels and their variation. If logistic considerations permit, it may be prudent to apply a sequential sampling approach. Under this scheme, estimates obtained from the early portion of the study are used to refine the sample size for the latter part.

Once preliminary estimates of $\overline{X}$ and S have been made, the required sample size, N, can be approximated. The formula for sample size will depend on whether the study has estimation or hypothesis-testing goals. A typical estimation goal is to estimate the average pollutant levels under prescribed conditions with a stated degree of precision. A typical hypothesis-testing goal is to compare pollutant levels from two differing sets of sampling conditions (e.g., two different types of structures) in order to test whether one of the conditions is associated with higher levels. The chances of arriving at incorrect conclusions on the basis of a statistical test are related to the chosen sample size.

In the case of estimation goals, a common statement of desired precision is as follows: "We wish to have a 95 percent confidence that the average level for the pollutant under consideration can be estimated within ± 10 percent of its true value for the chosen sampling conditions." The formula for the sample size necessary to meet this objective is as follows:

$$N = \frac{t^2 S^2}{d^2} \qquad (11)$$

where t represents the number of standard deviations (approximately two) that account for the central 95 percent of the area under a normal curve

S is the standard deviation for the variable to be estimated

d is the margin of error (i.e., 10 percent of the true value).

The value for t in the above expression will vary with the confidence level of choice. Given a confidence level, the approximate value for t can be found in an appendix of most statistical texts. As stated previously, best estimates of S and $\overline{X}$ are also required. The ratio $S/\overline{X}$ varies with sampling conditions but usually lies between 0.25 and 1.0 for CO, NO_2, and TSP. The ratio could be considerably larger for organic pollutants.

If, for example, best estimates indicate that $S/\overline{X} = 0.5$, then $0.5\overline{X}$ can be substituted for S in the above expression. Because $t = 2$ and $d = 0.1\overline{X}$ (i.e., 10 percent of the mean value), the required sample size is estimated as follows:

$$N = \frac{(2)^2(0.5\overline{X})^2}{(0.1\overline{X})^2} = \frac{4 \times 0.25\overline{X}^2}{0.01\overline{X}^2} = 100 \qquad (12)$$

Thus, for this hypothetical example, 100 air samples would be required in order to achieve the desired precision.

When two sets of sampling conditions are to be statistically contrasted, a t-test is commonly used to test the null hypothesis that their concentration distributions arise from the same underlying distribution. Sample size estimates can often be obtained from the t-test specification, which has the following general form:

$$t = \frac{\overline{X}_2 - \overline{X}_1}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \qquad (13)$$

where $\overline{X}_1$ and $\overline{X}_2$ are the mean concentrations for the two sets of sampling conditions

S is the standard deviation for the two sampling conditions

n_1 and n_2 are sample sizes for the two sampling conditions.

One important property of a statistical test is its power. The power is the probability that a statistical test will detect a true difference in pollution levels for the two differing sampling conditions. One minus the power is the probability (β) of making a Type II error, i.e., concluding that two different sampling conditions have the same underlying concentration distributions, when in fact they do not. The power of a statistical test increases as the size of the true, but unknown, difference between two sampling conditions increases. The other type of error is a Type I error, i.e., concluding that two sampling conditions have different underlying distributions, when in fact they do not.

Type I and II errors cannot be totally suppressed. For a fixed sample size, as α (probability of a Type I error) decreases, β (probability of a Type II error) increases, and vice versa. Thus, the sample size of choice and the α and β levels at which a statistical test is conducted are closely intertwined. Once two of these parameters are specified, the third is automatically determined. When providing study results, it is customary to report the level of significance (α level) at which the statistical test was conducted.

The α level for a statistical test should be specified before sampling is initiated. In choosing this level, one must carefully consider the anticipated error associated with the α level and the sample size of choice. Depending on the situation, the consequences of Type I errors, Type II errors, or both, many be of genuine concern. In the above formula, both $\overline{X}_2$ and S can be expressed in relation to $\overline{X}_1$. Power curves found in statistical tests (e.g., Dixon and Massey 1969, p. 14) can be used to relate the Type I and Type II errors associated with various sample sizes and assumed percentage differences between $\overline{X}_2$ and $\overline{X}_1$. The consequences of each type of error must be considered in choosing a sample size that will yield tolerable error levels.

The two cases provided in Table 5 as examples illustrate the considerations involved in choosing the appropriate sample size and level of significance for statistical testing. For both cases, it is assumed that $\overline{X}_1/S = 0.5$. In the first case, a test is required to assess whether the two sets of sampling conditions yield average pollution levels that differ by 25 percent or more. If 100 measurements are taken under each condition, then both α (0.05) and β (0.06) levels can be kept low. In the second case, a test to detect a smaller difference (10 percent or more) is required. In this case, 100 measurements for each condition do not appear to yield acceptable error probabilities. If 400 measurements for each condition are taken, then α and β can be equalized at reasonably low levels (0.10 and 0.11, respectively). If the test is performed at the 5 percent level of significance (i.e., $\alpha = 0.05$), then a β level of 0.19 can be anticipated.

Select Types of Instrumentation

Based on the review of instrumentation (Step 2), sample size (Step 5), and initial design (Step 4), users can begin to select monitoring instruments, methods, and equipment. This preliminary selection can yield a variety of

Table 5. ESTIMATED α AND β LEVELS ASSOCIATED WITH SELECTED SAMPLE SIZES AND ASSUMED DIFFERENCES BETWEEN $\overline{X}_1$ AND $\overline{X}_2$

Case 1. Test to Detect Whether $\overline{X}_1$ and $\overline{X}_2$ Differ by 25 Percent

Sample Size		Error Probabilities	
n_1	n_2	α	β
50	50	0.05	0.30
50	50	0.10	0.19
50	50	0.20	0.11
100	100	0.05	0.06
100	100	0.10	0.03
100	100	0.20	0.01

Case 2. Test to Detect Whether $\overline{X}_1$ and $\overline{X}_2$ Differ by 10 Percent

Sample Size		Error Probabilities	
n_1	n_2	α	β
100	100	0.05	0.70
100	100	0.10	0.59
100	100	0.20	0.44
400	400	0.05	0.19
400	400	0.10	0.11
400	400	0.20	0.07

equipment and methods for measuring air exchange and certain pollutants such as carbon monoxide. Therefore, users should consider the entire range of personal, portable, and fixed monitors, as well as active versus passive instrumentation, and all the associated cost advantages and disadvantages.

A two-stage screening approach can streamline the selection process. The first screening should concentrate on identifying measurement systems that are compatible with the needs of the study. The second screening should concentrate on developing the cost of acquisition and operational support.

Figure 3 presents the minimum factors that should be included at the first level of screening. Minimum technical requirements include the following:

- Instrument Mobility--With the use of the classification system introduced earlier, is the monitoring approach strictly limited to only one class of mobility (i.e., personal, portable, stationary), or can two or even all three classes work as well?
- Lower selection limit--Is the system sensitive enough to consistently measure the lowest levels potentially required by the problem?
- Range--Is response flexible enough to consistently measure concentrations above levels of concern?
- Reporting frequency--Is the output consistent with data needs (i.e., peaks versus time-weighted averages versus time series)?
- Unattended monitoring period--Does the instrument sample for sufficiently long time intervals?

The first screening level presents an important opportunity to adjust the study design if problem parameters cannot be measured by available technologies.

Summaries of commercially available instruments and user-configured methods are presented in Appendixes A and B to aid in the first level of screening. Instruments or methods that meet or exceed criteria established by the first screening level can then be reviewed for compatibility with technical resources.

	Commercially Available Instruments		User-Configured Methods	
Instrument/Method (reference from Appendixes A and B)				
1.1 Instrument Mobility				
Personal				
Portable				
Stationary				
1.2 Lower Limit of Detection				
Meets Requirements				
Exceeds Requirements				
Unacceptable				
1.3 Range				
Meets Requirements				
Exceeds Requirements				
Unacceptable				
1.4 Reporting Frequency				
Meets Requirements				
Exceeds Requirements				
Unacceptable				
1.5 Monitoring Period				
Meets Requirements				
Exceeds Requirements				
Unacceptable				

Figure 3. Worksheet for first-level screening of instrument selection.

As shown in Figure 4, the minimum factors that should be considered at the second screening level include the following:

- Acquisition costs--Are they acceptable?
- Staff resources--Are the currently available staff capable of operating the equipment? Is training feasible, or should the staff be augmented?
- Facilities--Are the facilities adequate to operate, repair, and calibrate the system, or is augmentation indicated?
- Permanence--Is it desirable that equipment have reliable service life after monitoring is complete?

If two or more instruments emerge from the screening with equal scores, additional factors of performance (i.e., rise time, zero and span drift), ease of maintenance, and options can guide selection.

Develop Initial Cost Estimates

Early in the design process, users will find it helpful to develop initial estimates of costs and other resource requirements. The estimates can be based on the total number of samples, the duration of each measured parameter, costs of instrumentation and analysis, study duration, costs of labor, and other costs. Users can later develop more detailed, precise estimates in Step 9.

Feedback

Based on initial projections of total costs, the scope of design can be expanded or reduced to match available resources. Often users will need to reduce the costs and, in turn, reduce the scope. Some reduction may be achieved with a reexamination of assumptions and needs for each of the nine steps. Alternatively, the feedback process can be restricted to reevaluating types of instruments (Step 6) and selecting less expensive types and numbers of instruments. If no changes to the preferred instrumentation package are desired, the only way to reduce costs may be to accept a smaller sample size. In some cases, it may be possible to expand available resources to match the desired scope.

Finally, another type of feedback should be an integral part of the design. This feedback relates to prompt analysis of data collected early in a monitoring program. The promptness of the analysis will substantially improve the chances of achieving the study objectives in a cost-effective manner.

	Commercially Available Instruments		User-Configured Methods	
Instrument/Method				
2.1 Acquisition Costs				
2.2 Staff Resources				
• Technical expertise acceptable				
• Training indicated				
• Staff preparation indicated				
2.3 Facilities				
• Support equipment adequate				
• Expansion indicated				
2.4 Permanence				
• Additional technical inventory desirable				
• Additional technical inventory undesirable				

Figure 4. Worksheet for second-level screening of instrument selection.

Develop Detailed Design and Cost Estimates

The detailed design for monitoring in Step 9 is the culmination of all the preceding steps discussed in this section. This step ties together the instrumentation preferences and the sample size requirements. The details concerning the selection and enrollment of sampling units must be specified. These details include the duration of monitoring for each sampling unit and, by extension, the overall monitoring schedule. These details will assist users in assessing the logistics needed to accommodate the monitoring strategy.

Cost estimates for personnel will also be needed. The following types of personnel may be required to implement the monitoring design and analyze the resultant data:

- Field Staff
    - Coordinators/managers
    - Technicians/interviewers
- Laboratory Staff
    - Laboratory scientists
    - Laboratory technicians
- Office Staff
    - Manager
    - Environmental scientists
    - Statisticians
    - Computer programmers
    - Scientific support personnel.

Other potential cost elements for the design are as follows:

- Instrumentation
- Laboratory analysis
- Quality control and quality assurance
- Field travel
- Incentives for monitoring participants
- Data processing
- Forms and reports.

When sufficient design details (e.g., number and locations of sampling units, duration of sampling interval, and enrollment rates) are specified, the user can estimate cost elements with reasonable precision.

PROBE PLACEMENT

The selection of a location for a probe, i.e. the point in the indoor space where the sample is taken, is extremely important in obtaining measurements that will meet desired design objectives previously discussed. The design objectives can be viewed from three general perspectives:

1. To characterize levels of indoor pollutants and to examine responsible factors

2. To quantitate exposure levels

3. To determine causes of indoor air quality problems.

The first two are somewhat similar: Pollutant characterization relates to determining "average" concentration for the air space under consideration, and exposure quantitation involves determining average concentration experienced by an individual occupying the air space. The third is oriented toward identifying or assessing the causes of indoor air problems, and thus average concentration or average exposure is less important. While probe placement considerations can be discussed for objectives based on characterization or exposure, the current state of knowledge limits similar considerations for determining causes of indoor air quality problems.

Selecting the probe location is a two-step procedure. The first step is to select a zone for monitoring, i.e., either a general area such as an upper floor or rooms such as the kitchen or a bedroom. The second step is to select a specific location within that zone.

In characterization studies, the selection of zones may be implicitly specified in a study objective. Even if zones are not specified, identifying candidate zones is a fairly straightforward process. It involves inspecting each area for indoor sources associated with the study objectives. Concentrations within a zone are dependent on sources present in that zone. Thus, if the objectives include examining the impact of specific indoor sources, then a zone that includes such sources will be important.

In studies involving occupied structures, a parallel interview or questionnaire greatly aids in identifying added factors that influence concentration levels. These factors may include potential interferents and habit patterns. For exposure-based studies, the selection of indoor monitoring zones is strictly tied to occupancy patterns. However, if the monitoring strategy entails personal monitoring, probe placement considerations may not be necessary.

A preferred but more resource-intensive approach for zone selection is to conduct premonitoring surveys (Nagda and Koontz 1983). In these surveys, simultaneous measurements of tracer gas decay at a number of indoor locations are employed to examine zone-to-zone differences in air exchange rates. As summarized in Woods and Maldonado (1982) probe placement can be guided by ranking indoor zones in terms of air exchange characteristics and indoor sources. One of the following cases will often be encountered:

- Indoor zones that exhibit relatively lower air exchange rates and that also contain indoor sources or communicate with zones that contain sources. Such zones will tend to have relatively higher concentrations than other zones when indoor sources are active.
- Indoor zones that exhibit relatively lower air exchange rates and that are generally isolated from indoor sources. Such zones are least influenced by indoor sources and would also have a time lag under the influence of outdoor concentrations.
- Indoor zones that exhibit relatively higher air exchange rates that are also free of indoor sources. Such zones will be principally influenced by outdoor concentrations.
- Indoor zones that exhibit relatively higher air exchange rates and that also contain (or communicate with) indoor sources. Such zones will be influenced by both indoor and outdoor sources, though concentrations attributable to indoor sources would be lower than in the first case above.

Based on specific objectives one or more such zones can be selected. For example, assessing influence of indoor source Case 1 above may be more useful than Case 4. On the other hand, influence of outdoor sources can be easily quantified for Case 3.

Once indoor zones have been identified, probe locations may be selected. Some guidelines for selecting probe locations include the following:

- Avoid exterior walls and corners
- Avoid areas that receive direct sunlight
- Avoid palpable drafts
- Avoid direct influence of supply or return ducts
- Avoid mounting heights below 3 feet or above 5 feet
- Avoid well-trafficked spots
- Avoid direct impact from sources.

To determine the causes of indoor air quality problems where average concentration or average exposure are generally not important, some of the above guidelines for selecting probe location may need to be revised or even reversed. For example, if the indoor air quality problem is known to exist in one area served by an air handling system, a sample may need to be taken in that area at a point directly influenced by the vents rather than at a location not directly influenced by the vents.

Finally, many indoor air quality studies require simultaneous measurements of outdoor concentrations. Probe siting criteria have been established in this respect (EPA 1979). However, such criteria may need to be selectively compromised because indoor air quality studies focus on the nearby outdoor air that infiltrates into the structure, while most ambient outdoor monitoring is concerned with the representation of a larger region.

ADDITIONAL READING

A number of documents describe the design of various indoor monitoring programs. To more fully understand the discussion presented in this section, users may refer to the documents listed below. Because design documents are not published as final reports, these may have to be obtained from the respective organizations.

- CPSC Protocol for Indoor Air Monitoring Project at Oak Ridge National Laboratory. 1982. Consumer Products Safety Council (Dr. K. Gupta), Bethesda, Md.
- Research Triangle Institute. 1982. "Workplan for the EPA FY82 Indoor Air Quality Research Program." U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.
- GEOMET Technologies, Inc. 1981. Field Measurements Program for Residential Indoor Air Quality Impact of Bonneville Power Administration Regionwide Weatherization Program, Report ES-922, Rockville, Md.
- Nagda, N.L., M.D. Koontz, and H.E. Rector. 1982. Workplan for Energy Use, Infiltration, and Indoor Air Quality in Tight, Well-Insulated Residences. Electric Power Research Institute. Prepared by GEOMET Technologies, Inc., Rockville, Md.

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Dixon, W.J., and Massey, J.J., Jr. 1969. Introduction to Statistical Analysis. McGraw-Hill Book Company. New York, N.Y.

Kreiss, K. "Building-Associated Epidemics," Chapter in Indoor Air Quality. Editors P.J. Walsh, C.S. Dudney, and E.B. Copenhaver. CRC Press. Boca Raton, Fla., in press.

Nagda, N.L., and M.D. Koontz. 1983. Energy Use, Infiltration, and Indoor Air Quality in Tight Well-Insulated Residences--Some Results of Prebaseline Monitoring. Prepared for Electric Power Research Institute. Prepared by GEOMET Technologies, Inc., Rockville, Md.

U.S. Environmental Protection Agency. 1979. Ambient Air Quality Monitoring, Data Reporting and Surveillance Provision. Appendix E: Probe Siting Criteria for Ambient Air Quality. Federal Register (44)92:27592-97.

Woods, J.E., and E.A.B. Maldonado. 1982. Development of a Field Method for Assessing Indoor Air Quality in Single Family Residences. Engineering Research Institute, Iowa State University, Ames, Iowa.

SECTION 6

DATA REPORTING

Unfortunately, much of the data collected in indoor air studies may not have been preserved. The organizations that sponsor studies generally lack either the mandate or the resources needed to continue data management activities when a study ends. Nor is there a central clearinghouse to store and disseminate the generated data. As a result, the only enduring record lies in the literature in which accounts of the studies are published. These accounts may present only a part of the data base.

Viewed from the narrow perspective of meeting study goals, the practice of not preserving the entire data base is probably satisfactory. But when viewed from the broader perspective of risk assessment and problem definition, any loss of data is regrettable.

This section provides general guidelines for two levels of data reporting:

- LEVEL I--Meeting Objectives of Specific Studies
- LEVEL II--Preserving Data for Use in Other Studies.

LEVEL I REPORTING: MEETING OBJECTIVES OF SPECIFIC STUDIES

Given the diversity of objectives and monitoring approaches for indoor monitoring studies, it may be impossible to give a detailed guide for reporting data. The difficulty is further compounded by continuing improvements in our understanding of factors responsible for indoor air quality. The evolution may require additional parameters to be included or different strategies to be used for monitoring, and fixed data reporting formats may unnecessarily hamper research progress.

Although it is impossible to report all collected data, investigators can follow minimum reporting requirements that might prove helpful to others. The minimum reporting requirements should address the tests applied to the data as follows:

- Descriptive Statistics--Means, standard deviations, and histograms or cumulative frequency plots are particularly important if nonparametric tests are used. In all cases, the number of data points involved in any descriptive statistic should be clearly stated.
- Hypotheses to be Tested--Exact statements of the null and alternative hypotheses will prove useful.

- Test Statistics--A listing of test values for successful as well as unsuccessful tests should be reported.

- Level of Significance--The probability that a rejected null hypothesis is true should be included in the reported data.

LEVEL II REPORTING: PRESERVING DATA FOR USE IN OTHER STUDIES

In the absence of a central repository for indoor air quality data, a cooperative approach is needed to ensure wider use of collected data. Within this approach, investigators should identify the scope of collected data in a common format. The intent here is to provide a means of rapidly screening studies for useful content by other interested researchers. Investigators can then obtain more detailed information on those data bases of interest by contacting the principal investigator of a study. The investigators will, thus, maintain their own actual data sets, compensating for the lack of a common repository.

A general descriptive format for reporting scope and content of data bases, which will accommodate a wide variety of indoor air quality studies, contains two separate information matrices. The first format, shown in Figure 5, offers a concise summary of key factors of the study and its design. The format organizes the study information useful for screening so that a user can easily identify the general study approach and the types of data collected. Most important, the format indicates the availability of those data.

The format of the data base content in Figure 6 enables a user to further identify factors surrounding collection and storage of data for each parameter. Thus, for each parameter, the following information is made available:

- Placement--Number of fixed indoor, outdoor, personal, mobile, or portable devices

- Raw Data--Form of collection (i.e., strip chart, data logger, worksheet), collection frequency (i.e., continuous, hourly, etc.), duration (i.e., the number of hours of sampling), and smallest time increment (i.e., duration of individual noncontinuous samples)

- Data Reduction--Principal averaging period (i.e., hourly, 24-hour, etc; this may be the same as the "smallest time increment" under raw data), and the number of data points per average

- Data Storage--Raw field records, worksheets, tabular summaries, computer tape, or active computer disk files.

TITLE: ____________________

PERFORMING ORGANIZATION: ____________ Principal Contact ________

SPONSORING ORGANIZATION: ____________ Principal Contact ________

PERIOD OF PERFORMANCE: ____________________

OBJECTIVES: ____________________

DATA RECORDS AVAILABLE UNTIL: ____________________

TYPE OF STUDY:
☐ Indoor Characterization
☐ Emission Characterization
☐ Exposure Characterization
☐ Impact of Weatherization
☐ Impact of Controls
☐ Modeling
☐ Building Associated Problems
☐ Other ________

LOCATION(S): ____________________

____

NUMBER OF STRUCTURES: ___ Residences ___ Offices ___ Other buildings

NUMBER OF STUDY PARTICIPANTS: ___ Individuals

AGE GROUP: ___ Adults ___ Children

SUMMARY OF APPROACH ____________________

____

____

DATA SUMMARY

1. INSTRUMENTED MEASUREMENTS

☐ Indoor Pollutants: ____________________
☐ Outdoor Pollutants: ____________________
☐ Indoor Environment (Temperature, humidity, etc.) ____________
☐ Air Exchange: ________ Mechanical Ventilation: ________
☐ Energy Consumption: ____________________
☐ Meteorology: ____________________

2. ADDITIONAL DATA COLLECTED

☐ Architectural/Structural: ____________________
☐ Individuals' Profile: ____________________
☐ Activity Patterns: ____________________
☐ Complaints: ____________________
☐ Interviews: ____________________

STUDY PUBLICATIONS: ____________________

____

____

Figure 5. Format for reporting key factors of an indoor air quality study and its design.

	Placement				Raw data									Reduced data		Storage and retrieval					
						Frequency#		Duration#		Smallest time increment#		Principal averaging period#								
Parameter & Instrument Designation	No. of fixed indoor	No. of fixed outdoor	No. of personal	No. of mobile/portable	Primary field record*	No.	Per	No.	Time	No.	Time	No.	Time	No. of points per average	Primary storage	Secondary storage	Restrictions**	Availability##	Comments

Notes:

* R = strip chart, L = data logger, W = worksheet.
# C = continuous, S = second, H = hour, D = day.
I = inactive/computer compatible, A = active/computer compatible, T = tabular summaries, X = raw data only.
** P = proprietary, K = confidential, U = unrestricted.
## M = paper copies only, Q = computer compatible.

Figure 6. Format for reporting scope of data collection and storage.

Each format fits on a single page, so that it is easy to handle, store, and disseminate.

The data base summary describing scope and content should become an integral part of publications and proceedings of symposia. This cooperative system would assist other users of the data base and help them recognize available data.

SECTION 7

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are measures used to ensure that procedures, equipment, personnel, and all other components of a monitoring program produce data of acceptable reliability. QC refers to routine procedures that ensure a reliable measurement process, while QA addresses the overall operations including planning, assessment, and corrective actions.

Both QA and QC provisions are implemented through a QA plan. The plan specifies in detail the manner in which a particular project or continuing operation will achieve predetermined goals of data quality. Often, a policy or regulation will require a QA plan. Even if a QA plan is not formally required, however, the process of developing a plan will force an investigator to review every aspect of operations in an orderly manner, thus strengthening the approach and resultant data.

The EPA has published a document to guide in preparing QA plans:

> U.S. Environmental Protection Agency. 1980. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. EPA QAMS-005/80, Office of Monitoring Systems and Quality Assurance, Office of Research and Development, Washington, D.C.

This document presents the principal elements of QA plans for environmental measurements and covers all aspects of indoor air quality monitoring. The following description, drawn largely from the EPA document, summarizes the elements of a QA plan. This section also presents examples of QA plans prepared for two different EPA projects.

ELEMENTS OF A QUALITY ASSURANCE PLAN

A quality assurance plan is a document composed of 16 items, as follows:

1. Title page, which includes provision for signatures indicating approval of the plan by the cognizant project manager, QA officers, and sponsoring organization

2. Table of contents

3. Project description

4. Project organization and responsibility

5. QA objectives

6. Sampling procedures
7. Custody procedures
8. Calibration procedures
9. Analytical procedures
10. Data reduction and reporting
11. Internal QC checks
12. Performance and system audits
13. Preventative maintenance
14. Assessment of data quality
15. Corrective actions
16. Quality assurance reports to management.

Generally all these items apply to indoor air quality monitoring studies. Many of the items are self-explanatory; other items--such as QA objectives, custody procedures, internal QC checks, performance and system audits, assessment of data quality, corrective actions, and QA reports--are discussed briefly below.

Quality Assurance Objectives

For each measurement variable, QA objectives should be defined in terms of the following:

- Accuracy, i.e., the degree of agreement of a measurement with an accepted reference or true value
- Precision, i.e., a measure of mutual agreement among individual measurements under prescribed conditions
- Completeness, i.e., a measure in percent of the amount of valid data recovered, as compared with expectations
- Representativeness, i.e., an expression of the degree to which data accurately and precisely represent key characteristics or conditions
- Comparability, i.e., an expression that defines the degree of confidence with which one data set can be compared with another.

Custody Procedures

Custody procedures, primarily used when many samples are involved, clearly document the paths taken by all relocatable elements. A relocatable element is any item that affects the final data product, such as sample media, primary data, and reduced data records. Where appropriate, each relocatable element receives a unique identity, including serial number, date, time, and location. A log documents the movement of the element among various points of custody--technical personnel, files, and storage. Such tracking, which provides safeguards against data loss, is particularly useful in determining sources of contamination or other adverse factors that might jeopardize the quality of data.

Internal QC Checks

Internal QC checks consist of periodic testing of equipment performance and assessment of procedures. For approaches relying on sample collection and laboratory analysis, the following types of checks should be considered: (1) replicates, (2) spiked samples, (3) split samples, (4) blanks, and (5) reagent checks. The QC checks should be applied to all procedures and equipment for direct reading instruments and should include either use of a standard reference for challenging the device or colocating a portable reference analyzer for comparing the readings.

Performance and System Audits

Investigators should periodically conduct performance audits to determine the accuracy of the total measurement system and its individual components. Most aspects of a peformance audit are similar to those of the internal QC checks except that performance is verified through standards, devices, and personnel, which are independent of the routine project organization and equipment.

Systems audits consist of a qualitative evaluation of the facilities, equipment, training, procedures, recordkeeping, data validation, and reporting aspects of the total monitoring approach. This evaluation provides a measure of the capability to perform within QA objectives.

Both performance and systems audits should precede initial data collection. Thereafter, the frequency of audits would be dictated by policy, objectives, and resources.

Assessment of Data Quality

For each major measurement parameter, the QA plan should address routine procedures to assess precision, accuracy, and completeness of the accumulating data. The results of the assessment must be continually tested against QA objectives.

Corrective Action

Corrective actions are the systematic response to errors, malfunctions, and other deficiencies. Corrective actions may stem from the following:

- Excursions of data quality to unacceptable levels
- Results of internal QC checks
- Results of performance or systems audits.

The QA plan should stipulate procedures to be followed in correcting a deficiency. Regardless of the size of the deficiency or actual need for corrective action, three steps must be followed:

1. Analysis--To determine potential causes, extent of negative impact on accumulated data, and reasonable corrective actions.
2. Adjustment--To transmit corrective steps to cognizant personnel, to adjust affected data, to label the data as questionable, or to discard.
3. Report--To document the entire corrective operation in the permanent records.

Quality Assurance Reports

The QA plan should include provisions for periodic reports on systems and data quality. Such reports should include the following:

- Assessment of accuracy, precision, and completeness
- Results of performance and systems audits
- Significant problems and solutions.

Such reports may be required on a predetermined schedule or solely in response to problems or special events.

EXAMPLES OF QUALITY ASSURANCE PLANS

The investigator may find it useful to review QA plans prepared for other studies. Below are two exemplary documents:

- Research Triangle Institute. 1981. Total Exposure Assessment Methodology (TEAM) Study: Phase II/Part III:

Quality Assurance Project Plan. Prepared under Contract No. 68-02-3679, U.S. Environmental Protection Agency, Research Triangle Park, N.C.

This document is a model example of an operational QA plan. It follows closely the EPA guidelines and specifications. The plan is directed toward field sampling and laboratory analysis; but many, if not all, the items in the QA plan apply to direct field and/or laboratory measurements as well.

- Battelle Columbus Laboratories. 1982. Quality Assurance Plan for Control Technology Assessment and Exposure Profile for Workers Exposed to Hazards in the Electronics Component Industry. Prepared under Contract No. 68-03-3026, U.S. Environmental Protection Agency, Columbus, Ohio.

This is another model QA plan prepared for a study, jointly funded by EPA and NIOSH, to assess human exposure to air pollutants on a 24-hour-a-day basis. This study will be conducted in the electronic components industry. The NIOSH portion of the study is concerned with assessing worker exposure from job-related activities. The EPA portion is concerned with the more ubiquitous air pollutants to which people--in this case, electronics industry workers--are continually exposed. The document presents the QA plan for the EPA 24-hour exposure study.

Appendix A

SUMMARIES OF INSTRUMENTS

INTRODUCTION

This appendix reviews commercially available instrumentation suitable for indoor air quality monitoring. As defined in Section 4, instruments are as follows:

1. Mobility
   - Personal
   - Portable
   - Stationary

2. Power Requirements
   - Active
   - Passive

3. Output Characteristics
   - Analyzer
   - Collector

These terms can be assembled to form 12 distinct instrument categories such as PERSONAL/PASSIVE/COLLECTOR and STATIONARY/ACTIVE/ANALYZER. Key performance characteristics of these instruments are summarized within a format derived from an extensive survey of environmental monitoring instrumentation begun by the Lawrence Berkeley Laboratory in the 1970s. Where there was no information available for certain characteristics such as "lagtime" as in case of ECOLYZER Model 2000, the entry was left blank. A glossary defining key instrument terms appears at the end of this appendix.

In offering this appendix, the intent is primarily to summarize alternatives among PERSONAL, PORTABLE, and STATIONARY instruments for each pollutant. This was not possible for some pollutants (Table 4). Appendix B summarizes approaches that can fill some of the voids.

In response to the National Ambient Air Quality Standards, a large number of STATIONARY/ACTIVE/ANALYZERS are available for carbon monoxide, nitrogen dioxide, sulfur dioxide, and ozone. Instruments for these pollutants that appear on the EPA-designated list of reference and equivalent methods for these pollutants are listed in a subsection of this appendix.

INSTRUMENTS

The following pages present summaries of 35 measuring instruments and 3 data logging devices. In the majority of the cases, individual summaries have been reviewed by manufacturer representatives. Price information cited in this appendix is current to late 1982 and subject to change.

ASBESTOS AND OTHER FIBROUS AEROSOLS
PORTABLE/ACTIVE/ANALYZER

1-1
GCA FAM-1
Fibrous Aerosol Monitor
1 of 3

Weight: 11.4 kg

Dimensions: 53 x 35 x 20 cm

Principle of Operation:	Induced oscillation/optical scattering. Sample air passes through a laminar flow chamber and enters a sensing region where an oscillating electric field induces fiber oscillations. The sensing region is illuminated by a continuous wave He-Ne laser that is aligned with sample flow. Scattering pulses from fiber oscillation are detected by a photomultiplier positioned at right angles to the laser. Electronic circuitry applies four separate acceptance tests to discriminate fibers, producing fiber counts per cubic centimeter.
Lower Detectable Limit:	0.001 fibers/cm^3; minimum detectable fiber length: 2 μm; minimum detectable fiber diameter: 0.2 μm
Range:	0.001 to 30 fibers/cm^3
Interferences:	Large concentrations of elongated particles
Multiparameter Capability:	Fiber counts only

Performance:

Sampling Rate: 2 l/min (adjustable 1.5 to 2.5 l/min), continuous; fiber counting and selectable at 1, 10, 100, and 1,000 minutes

Accuracy: equal to reproducibility when calibrated for specific fibers

Reproducibility: (one-sigma) +(100/N)%, (where N is the number of fibers counted)

Linearity: ±5% of count

Noise:

Lagtime: <0.5 seconds

Rise Time: 0

Retention Time: detection period = approx. 50 milliseconds

Fall Time: 0

Zero Drift:

Span Drift:

Operation:

Temperature Range: 0° to 50° C

Temperature Compensation: none

Relative Humidity Range: 0% to 95% for conductive fibers
30% to 95% for dielectric fibers

Calibration: factory set or field adjustable through comparison against NIOSH asbestos fibers method

Warm-Up Time: 5 minutes

Unattended Period: indefinite

Maintenance: occasional cleaning of optics

Power: 115 or 220 V a.c., 50 or 60 Hz; or may be run off battery power pack

Features:

Output: 6-digit LCD; recorder output

Training: 4 hours

Options: battery power pack; digital to analog interface (recorder output)

Costs:

FAM-1: $10,850
Battery power pack: $720
Digital analog interface: $830

Manufacturer:

GCA Corporation, Technology Division, Environmental Instruments
213 Burlington Road
Bedford, Massachusetts 01730

(617) 275-5444

References:

Specifications

1. Manufacturer's bulletin--9-80 cp 2.5M
2. Lilienfeld, P. 1979. "Development of a Prototype Fibrous Aerosol Monitor." Am. Ind. Hyg. Assoc. J. 4:270.

Operations experience

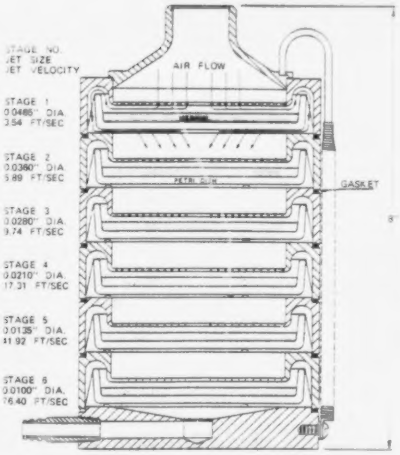
1. Elias, J.D. 1981. "Dry Removal of Asbestos." Am. Ind. Hyg. Assoc. J.
2. Page, S.J. 1980. Correlation of the Fibrous Aerosol Monitor with the Optical Membrane Filter Count Technique. U.S. Department of the Interior, Bureau of Mines Report.

Remarks:

A standard inline membrane filter permits concurrent collection of fiber samples.

BIOLOGICAL AEROSOLS
STATIONARY/ACTIVE/COLLECTOR

2-1
ANDERSEN
#10-800 VIABLE
SAMPLE KIT
1 of 3


STAGE NO.
JET SIZE
JET VELOCITY
AIR FLOW
STAGE 1
0.0485" DIA.
3.54 FT/SEC
STAGE 2
0.0360" DIA.
5.89 FT/SEC
PETRI DISH
GASKET
8"
STAGE 3
0.0280" DIA.
9.74 FT/SEC
STAGE 4
0.0210" DIA.
17.31 FT/SEC
STAGE 5
0.0135" DIA.
41.92 FT/SEC
STAGE 6
0.0100" DIA.
76.40 FT/SEC

Weight: 1.5 kg

Dimensions: 20 x 11 cm

Principle of Operation:	Impaction. Upon entering the inlet, sample air is accelerated through a series of six impaction stages, each of which holds a petri dish containing agar, which serves as the collection surface. Within each stage, jet velocity is uniform but increases in each succeeding stage. Each successive stage collects the larger particles remaining in the air stream. Microbial colonies are incubated for 24 hours and counted manually.
Lower Detectable Limit:	
Range:	
Interferences:	
Multiparameter Capability:	

2-1
ANDERSEN
#10-800 VIABLE
SAMPLE KIT
2 of 3

Performance:

Sampling Rate: 28.3 l/min, continuous
Accuracy:
Reproducibility:
Linearity:
Noise:
Lagtime:
Rise Time:
Retention Time:
Fall Time:
Zero Drift:
Span Drift:

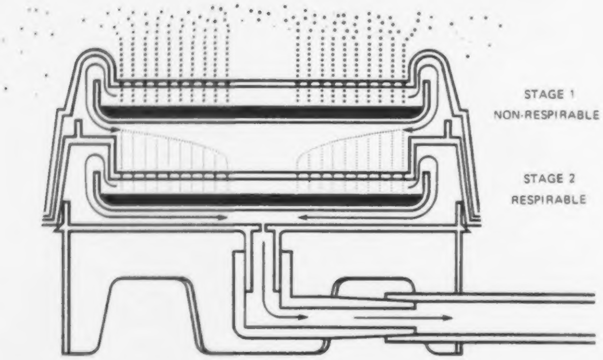
Operation:

Temperature Range:
Temperature Compensation:
Relative Humidity Range:
Calibration:
Procedure:
Warm-Up Time:
Unattended Period: usually <60 minutes (see remark #1)
Maintenance:
Power: 115 V a.c.

Features:	Output: Training: recommended Options:
Costs:	#10-800 Viable Sampler Kit (including pump and case): $2195
Manufacturer:	Andersen Samplers, Inc. 4215 Wendell Drive Atlanta, Georgia 30336 Toll free: (800) 241-6898 In Georgia: (404) 691-1910
References:	Specifications 1. Manufacturer's bulletin Operations experience 1. None available
Remarks:	Sample periods for biological aerosols are generally less than 60 minutes to avoid dehydration of collected microorganisms. Available time did not permit review of this summary by a manufacturer's representative. Pricing information has been verified by telephone.

BIOLOGICAL AEROSOLS
STATIONARY/ACTIVE/COLLECTOR

2-2
ANDERSEN
#10-850 TWO-STAGE
MICROBIAL SAMPLER
1 of 4



Weight: 1.5 kg

Dimensions: 20 x 11 cm

Principle of Operation:	Impaction. Upon entering the inlet, sample air is accelerated through a series of two impaction stages, each of which holds a disposable petri dish containing agar, which serves as the collection surface. The first stage collects particles larger than 7 μm. The second stage collects particles between 1 and 7 μm. Microbial colonies are incubated for 24 hours and counted manually.
Lower Detectable Limit:	
Range:	
Interferences:	
Multiparameter Capability:	

Performance:

Sampling Rate: 28.3 l/min, continuous

Accuracy:

Reproducibility:

Linearity:

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range:

Temperature Compensation:

Relative Humidity Range:

Calibration: none required in ordinary use (see remark #1)

Procedure:

Warm-Up Time:

Unattended Period: usually <60 minutes (see remark #2)

Maintenance:

Power: defined by user-supplied vacuum source

Features:

Output:

Training: recommended

Options:

Costs:

#10-850: $850

Manufacturer:

Andersen Samplers, Inc.
4215 Wendell Drive
Atlanta, Georgia 30336

Toll Free: (800) 241-6898

In Georgia: (404) 691-1910

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

A critical orifice situated in the base of the sampler provides constant flow of 1 CFM as long as vacuum is 10 inches of Hg.

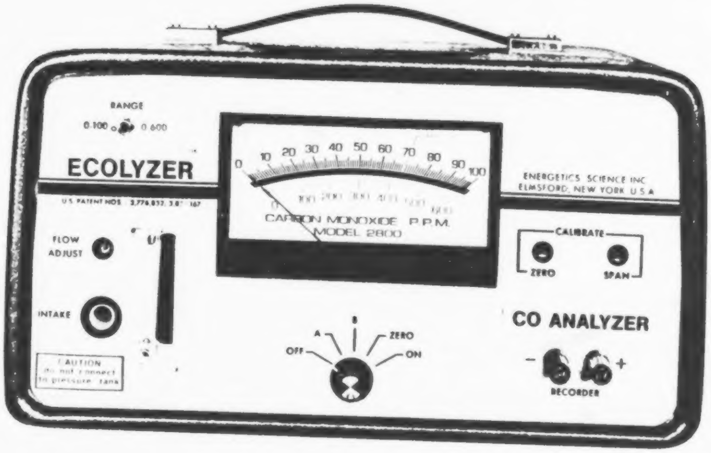
Sample periods for biological aerosols are generally less than 60 minutes to preclude dehydration of collected microorganisms.

The sampler uses disposable 100-mm petri dishes and is reusable and sterilizable.

Available time did not permit review of this summary by a manufacturer's representative. Pricing information was verified by telephone.

3-1
ECOLYZER
Model 2000
CO Monitor
1 of 4

CARBON MONOXIDE
PORTABLE/ACTIVE/ANALYZER


RANGE
0-100
0-600
ECOLYZER
U.S. PATENT NOS. 3,776,832; 3,8__,167
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600
CARBON MONOXIDE P.P.M.
MODEL 2800
ENERGETICS SCIENCE INC
ELMSFORD, NEW YORK U.S.A.
FLOW ADJUST
INTAKE
CAUTION do not connect to pressure tank
CALIBRATE
ZERO
SPAN
CO ANALYZER
OFF
A
B
ZERO
ON
-
+
RECORDER

Weight: 4.5 kg

Dimensions: 17.8 x 17.8 x 33 cm

Principle of Operation:	Electrochemical oxidation. Ambient air is drawn past a catalytically active electrode where CO is oxidized, producing a signal proportional to the CO concentration in the sample air stream. Potential interferents can be removed by an inlet scrubber.
Lower Detectable Limit:	<0.5 ppm
Range:	0 to 100 ppm, 0 to 600 ppm

Interferences:

ECOLYZER
Carbon Monoxide Specificity*

Interfering Gas	Concentration Tested (ppm)	Reading on Scale (ppm)
CH_4 (Methane)	50,000	No interference
CO_2 (Carbon Monoxide)	10,000	No interference
NH_3 (Ammonia)	500	No interference
NO (Nitric Oxide)	50	No interference
NO_2 (Nitrogen Dioxide)	25	No interference
N_2O (Nitrous Oxide)	100	No interference
C_2H_2 (Acetylene)	5	15
C_2H_4 (Ethylene)	10	10
C_2H_6 (Ethane)	10	0.10
C_3H_8 (Propane)	100	1.0
H_2 (Hydrogen)	50	0.5
H_2S (Hydrogen Sulfide)	50	0.5
SO_2 (Sulfur Dioxide)	100	1.0

* Tested with interference filters

Multiparameter Capability:

The model 7000 version of the instrument allows any two of the following to be paired in the same chassis: CO, NO_2, NO, and H_2S. While it would be attractive to pair CO and NO_2 for indoor air quality monitoring, the NO_2 monitor of the 200 series may be of limited use under current specifications because the most sensitive range is 0 to 2 ppm.

Performance:

Sampling Rate: 700 ml/min, continuous

Accuracy: ±1%

Reproducibility: ±1%

Linearity: 1%

Noise: ±0.2%

Lagtime:

Rise Time: approximately 25 seconds

Retention Time:

Fall Time: approximately 25 seconds

Zero Drift: <±0.5 ppm/day

Span Drift: 1%/day

Operation:

Temperature Range: 0° to 40° C

Temperature Compensation: see remarks

Relative Humidity Range: unaffected by water vapor

Calibration: standard gas mixture

Warm-Up Time: specified only as "brief"

Unattended Period: 8+ hours on battery

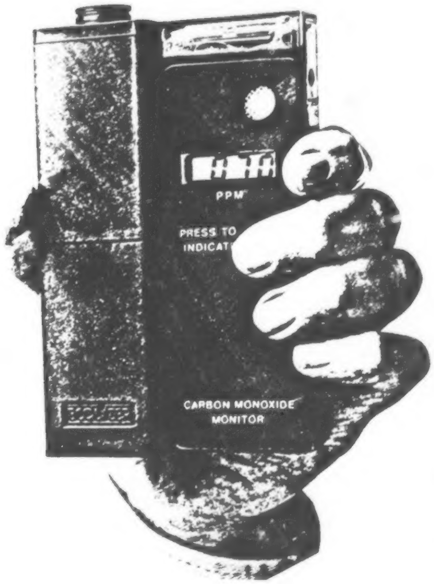
Maintenance: 1-year sensor warranty;
Boards replaceable in field

Power: 105-125 V a.c. at 50-60 Hz; Ni-Cd batteries with built-in recharger

Features:	Output: 0 to 100 ppm CO, 0 to 600 ppm CO panel meter with paralax mirror; 0- to 1-volt d.c. recorder output Training: none required for sampling Options: d.c.-powered recorder a.c.-powered recorder
Costs:	Model 2000 CO monitor: $1,900 DC recorder: $550 AC recorder: $450
Manufacturer:	Energetics Science, Inc. 6 Skyline Drive Hawthorne, New York 10532 (914) 592-3010
References:	Specifications 1. Manufacturer's bulletin Operations experience 1. Cortese, A.D., and J.D. Spengler. 1976. "Ability of Fixed Monitoring Station to Represent Personal Carbon Monoxide Exposures." J. Air Pollut. Control Assoc. 26:1144-50.
Remarks:	Low temperature (0-10° C) zero drift was found to be +1%-2% of scale over 30 minutes; calibration drift was <1 ppm (Cortese and Spenger 1976).

CARBON MONOXIDE
PERSONAL/PASSIVE/ANALYZER

3-2
ESI 210
Personal CO Monitor
1 of 3



Weight: 0.3 kg

Dimensions: 14 x 8.5 x 3.8 cm

Principle of Operation:	Electrochemical. Ambient air diffuses into a patented, three-electrode electrochemical cell.
Lower Detectable Limit:	1 ppm
Range:	0 to 1999 ppm
Interferences:	

Interferent Tested	Concentration Tested	Concentration Necessary to Yield 1 ppm Equivalent CO (ppm)
Methane	99%	No interference
Carbon Dioxide	99.8%	No interference
Ammonia	29.4 ppm	135
Nitric Oxide	48.2 ppm	No response
Nitrogen Dioxide	387 ppm	270
Sulfur Dioxide	21.2 ppm	145
Hydrogen Sulfide	27.2 ppm	130
Acetylene	100 ppm	170
Ethylene	19.4 ppm	135
Ethane	50 ppm, 500 ppm	1200 (no response at 50 ppm)
Propane	105 ppm	425
Methanol	500 ppm	No response
Ethanol	500 ppm	140
Propanol	500 ppm	750

Multiparameter Capability: CO only

Performance:

Sampling Rate: diffusion, continuous

Accuracy: ±5% or ±1 ppm (whichever is greater)

Reproducibility: ±2% or ±1 ppm (whichever is greater)

Linearity:

Noise:

Lagtime:

Rise Time: 16 seconds to 50 ppm, with a 200 ppm exposure

Retention Time:

Fall Time:

Zero Drift: <5 ppm/24 hr

Span Drift: ±2%/24 hr or 2 ppm/24 hr (whichever is greater)

Operation:

Temperature Range: 0° to 40° C

Temperature Compensation:

Relative Humidity Range: 5% to 90%

Calibration: standard gas mixture

Warm-Up Time:

Unattended Period:

Maintenance: batteries field replaceable;
6-month sensor warranty

Power: standard 9-volt transistor battery

Features: Output: LCD push button-activated or continuous display

Training: none required for sampling

Options: lapel clip-on alarm horn for high noise areas

Costs: Model 210: $695

Manufacturer:
Energetics Science Division of Becton
Dickinson and Company
Six Skyline Drive
Hawthorne, New York 10532

(914) 592-3010

References: Specifications

1. Manufacturer's brochure 2C-10-1-82

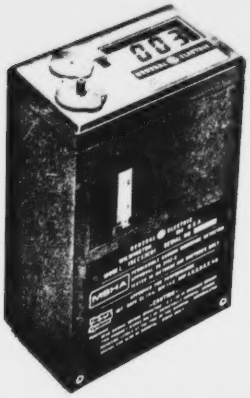
Operations experience

1. None available

Remarks: A similar version is available for H_2S.

CARBON MONOXIDE
PERSONAL/ACTIVE/ANALYZER

3-3
GENERAL ELECTRIC
CO DETECTOR
1 of 5



Weight: 290 g

Dimensions: 7.5 x 13.5 x 3.6 cm

Principle of Operation:	Electrochemical oxidation. Air is drawn through a filter and into an electrochemical cell in which oxidation of CO produces an electrical signal proportional to CO concentration in the air stream.
Lower Detectable Limit:	1 ppm
Range:	0 to 1000 ppm
Interferences:	(with Purafil filter installed)

Interferent Gas	Concentration In Air	Equivalent CO Reading (ppm)
Water Vapor	50% to 100%	0
O_2	16% to 20%	0
CH_4	3%	0
CO_2	1%	0
NO	50 ppm	0
NO_2	10 ppm	0
SO_2	25 ppm	0
H_2	100 ppm	0
C_2H_2	100 ppm	2
H_2S	10 ppm	16
C_2H_4	100 ppm	0
Electromagnetic (0-80 MHz)	3 volts/meter	18 No effect

Multiparameter Capability:	CO only	
Performance:	Sampling Rate:	60 ml/min, continuous
	Accuracy:	direct LCD readout, 0 to 500 ppm ±10% 500 to 1000 ppm ±15% accumulator, 0 to 10 ppm/hr ±2 ppm hr 10 to 500 ppm/hr ±10% 8 hr TWA 500 to 1000 ppm/hr ±15% 8 hr TWA
	Reproducibility:	±5%
	Repeatibility:	±5%
	Linearity:	0 to 500 ppm ±10% 500 to 1000 ppm ±15%
	Noise:	<0.5 ppm
	Lag Time:	6 seconds
	Rise Time:	<45 seconds
	Response Time:	within 2 minutes to 90%
	Retention Time:	6 seconds
	Fall Time:	<40 seconds
	Zero Drift:	very little, if any (usually ±1 ppm over several days)
	Span Drift:	generally ±5 ppm at 60 ppm span gas if several days elapse
Operation:	Temperature Range:	1° to 40° C (freezing conditions should be avoided)

Temperature Compensation: fully compensated over the range 1° to 40° C

Relative Humidity Range: 0% to 95% RH

Calibration: standard gas mixture

Unattended Period: 10 hours (4 hours with light and alarm on; starting with a fully charged battery). Unattended sampling may be greatly extended by running off battery charger if normal a.c. power is available (Model CO-3 only). See remarks below to extend unattended period of operation.

Warm-Up Time: 3 minutes (after 14-hour charge cycle)

Maintenance: purafil filter: renew upon color change
cell assembly: replenish distilled or de-ionized water periodically
storage conditions: 1° to 50° C

Power: 5.2 V d.c., 250 ma-hr, rechargeable Ni-Cd

Features:

Output: LCD panel readout (instantaneous levels)
recorder output 0 to 1 V d.c.
internal accumulator (requires external console to read out; see options)

Training: none required for sampling

Options: support console (to read/reset accumulator)
gas calibration kit
charger

Costs:

Direct indicating detector: $1,195
Support console: $775 (single charge); $935 (multicharge)
Gas calibration kit: $245
Charger: $29

Manufacturer:

General Electric Company
333 West Seymour Avenue
Cincinnati, Ohio 45216

(513) 948-5050

References:

Specifications

1. "Operation and Maintenance Instructions, Direct Indicating SPE Carbon Monoxide Detector." GE Aircraft Equipment Devices, 1980.
2. "Model 15ECS1C02 Carbon Monoxide Dosimeter and Model 15ECS3C03 Direct Indicating Carbon Monoxide Detector for Performance and Instrinsically Safe for Classes I and II, Divisions 1 and 2, Groups A, B, C, D, E, F, and G Hazardous Locations." J.I. 1A7A0. Ax (6340/3610) Factory Mutual Research, 1151 Boston, Providence Turnpike, Norwood, Massachusetts 02062. November 1979.

Operations experience

1. Flachsbart, P.G., and W.R. Ott. (In preparation). Field Surveys of Carbon Monoxide in Commercial Settings Using Personal Exposure Monitors. For U.S. Environmental Protection Agency.
2. Nagda, N.L., and M.D. Koontz. 1983. Exposures to Carbon Monoxide. Final Report No. EHF-1200, for Electric Power Research Institute. GEOMET Technologies, Inc., Rockville, Md.

Remarks:

These units may be leased from the manufacturer.

Alternative support consoles are available from additional sources; see entries under Data Logging.

The unattended period has been extended to well over 35 hours by substituting a larger capacity battery (see reference 2 listed under operations experience).

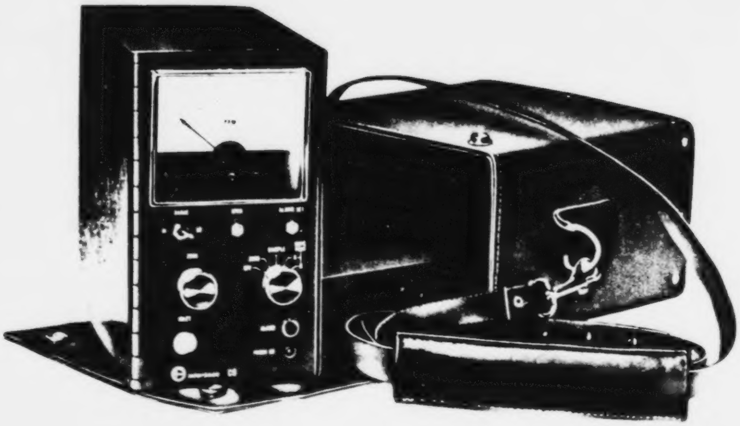
These units have been approved by the following organizations:

Mine Safety and Health Administration, U.S. Department of Labor. Permissible Carbon Monoxide Detector, Tested in Methane--Air Mixtures Only, Approval 2G-3152-1.

Factory Mutual System. Approved for Performance and Intrinsically Safe for Classes I and II, Divisions 1 and 2, Groups A, B, C, D, E, F, and G.

CARBON MONOXIDE
PORTABLE/ACTIVE/ANALYZER

3-4
INTERSCAN
CO 1140 and 4140
1 of 3



Weight: 3.6 kg (Model 1140)
2.0 kg (Model 4140)

Dimensions: 18.4 cm x 1.5.2 cm x 29.2 mm (Model 1140)
17.8 x 10.2 x 22.5 cm (Model 4140)

Principle of Operation:	Electrochemical. Gas molecules from the moving sample air stream pass through a diffusion medium and are adsorbed onto an electrocatalytic sensing electrode where subsequent reactions generate an electric current. The diffusion limited current is linearly proportional to CO concentration.
Lower Detectable Limit:	1% of full scale
Range:	0 to 100 ppm, 0 to 250 ppm, 0 to 500 ppm (other ranges available)
Interferences:	Expressed as ppm of interferent needed to give 1 ppm deflection:

H_2S:	>500	MeSH (Methyl mercaptan):	100
NO:	>500	EtSH (Ethyl mercaptan):	100
H_2:	125		

SO_3, NO, N_2O, NH_3, Me_2S, CO_2, and saturated hydrocarbons show no interference. Unsaturated hydrocarbons require a special filter when present in concentrations equivalent to CO.

Multiparameter Capability: CO only

Performance:

Sampling Rate: 1.2 l/min, continuous

Accuracy: ±2% of full scale

Reproducibility: ±0.5%

Linearity: ±1% of full scale

Noise:

Lagtime: <1 second

Rise Time: 20 seconds

Retention Time:

Fall Time: 20 seconds

Zero Drift: ±1% full scale in 24 hours

Span Drift: <±2% full scale in 24 hours

Operation:

Temperature Range: 10° to 120° F

Temperature Compensation: integral

Relative Humidity Range: 1% to 100%

Calibration: standard gas mixture

Warm-Up Time: <5 minutes

Unattended Period: 10 hours on battery power

Maintenance: calibration, battery replacement, biannual sensor replacement

Power: 1140: 4 Alkaline MnO_2 batteries for amplifier, 2 Ni-Cd for pumps and power-on LED, 1 HgO battery for bias amplifier reference

4140: No HgO battery is used; four "1/2C" Ni-Cd used

Features:

Output: 0-100 mV full scale

Training: none required for sampling

Options: alarms, special ranges

Costs:

Model 1140: $1,675
Model 4140: $1,895

Manufacturer:

Interscan Corporation
P.O. Box 2496
21700 Nordhoff Street
Chatsworth, California 91311

(213) 882-2331
TELEX: 67-4897

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. Ziskind, R.A., et al. 1981. "Carbon Monoxide Intrusion into Sustained-Use Vehicles." Environ. Int. 5:109-23.

Remarks:

CARBON MONOXIDE
PERSONAL/PASSIVE/ANALYZER

Model 5140
CARBON MONOXIDE DOSIMETER
interscan

Weight: 680 g

Dimensions: 152 x 76 x 51 mm

Principle of Operation: Diffusion/Electrochemical. Carbon monoxide diffuses into an electrochemical cell, producing a signal proportional to CO concentrations. The signal is digitized, incorporated into 1-minute averages, and stored. Nondestructive recovery of each 1-minute average is accomplished through a separate data reader. Data storage capacity is 2,048 1-minute averages.

Lower Detectable Limit: 2.5 ppm

Range: 0 to 1,000 ppm

Interferences: Expressed as ppm of interferant needed to give 1 ppm deflection:

H_2S: >500
NO: >500
H_2: 125
MeSH: 100
EtSH: 100

SO_3, NO, N_2O, NH_3, Me_2S, CO_2, and saturated hydrocarbons show no interference. Unsaturated hydrocarbons require a special filter when present in concentrations equivalent to those of CO.

Multiparameter Capability: CO only

Performance:

Sampling Rate: diffusion, continuous

Accuracy: ±2% of reading, ±1 least significant digit (LSD), ±0.5% of full scale

Reproducibility: ±1% reading, ±1 LSD

Linearity: 0.5% reading, ±1 LSD

Noise:

Lagtime:

Rise Time: 20 seconds

Retention Time:

Fall Time: 20 seconds

Zero Drift: ±1% reading, ±1 LSD in 24 hours

Span Drift ±1% reading, ±1 LSD in 24 hours

Operation:

Temperature Range: 30° to 120° F

Temperature Compensation:

Relative Humidity Range: 1% to 100%

Calibration: standard gas mixture

Warm-Up Time: <5 minutes

Unattended Period: up to 34 hours

Maintenance: calibration, battery replacement, sensor replacement

Power: long-life 9-volt battery (alkaline MnO_2 NEDA type 1604A); battery life is 125 hours continuous operation

Features: Output: printout from data reader (see remark #1)

Training: none required for sampling

Costs: $1,145; $275 for calibration meter

Manufacturer:

Interscan Corporation
P.O. Box 2496
21700 Nordhoff Street
Chatsworth, California 91311

(213) 882-2331
TELEX 67-4897

References: Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks: Data readout is accomplished by a device available from:

Metrosonics, Inc.
P.O. Box 23075
Rochester, New York 14692

(716) 334-7300

Interscan has also recently introduced the Model 2140 CO personal monitor that offers an LCD display of concentration instead of data logging.

4-1
Air Quality Research
PF-1
HCHO passive monitor
1 of 4

FORMALDEHYDE
PERSONAL/PASSIVE/COLLECTOR

Weight: negligible

Dimensions: 90 x 25 mm (diameter)

Principle of Operation:	Sorption/colorimetry. The sampler consists of a glass-fiber filter treated with sodium bisulfite, housed in a glass vial that is capped when not in use. Formaldehyde diffuses through the tube at a rate dependent upon Fick's First Law of Diffusion. The treated filter at the bottom end of the tube maintains a near-zero formaldehyde concentration at the base; therefore, the quantity of formaldehyde transferred through the diffusion path is related to the ambient concentration and the length of time exposed. Collected formaldehyde is quantified in the laboratory using the chromotropic acid procedure.
Lower Detectable Limit:	1.68 ppm-hr (0.010 ppm for 1-week exposure)
Range:	Validated over the range of 0 to 150 ppm-hr. Capacity established to be in excess of 1,000 ppm-hr.

Interferences: None known at this time. The analytical procedure (chromotropic acid) is subject to interference by several compounds, but they are seldom encountered in indoor air quality sampling applications. In any event the compounds are not expected to be collected by the bisulfite-treated filter collection element.

Multiparameter Capability: HCHO only

Performance:

Sampling Rate: 4.1 ml/min, continuous

Accuracy:

Linearity:

Noise:

Lagtime:

Reproducibility: ±25%

Rise Time: on the order of seconds

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range:

Temperature Compensation: none required for 15° to 35° C

Relative Humidity Range: noncondensing

Calibration: static laboratory standards (see third reference under specifications)

Unattended Period: 1 week (recommended minimum exposure for indoor studies)

Power: none

Features:

Output: laboratory report

Training: none required for sampling

Options:

Costs:

Sampler only: $15 for box of 2
Sampler plus analysis: $30 for box of 2

NOTE: These are nominal prices; actual costs depend upon lot sizes.

Manufacturer:

Air Quality Research, Inc.
901 Grayson Street
Berkeley, California 94710

(415) 644-2097

References:

Specifications

1. Manufacturer's bulletin
2. Geisling, K.L., et al. 1981. "A New Passive Monitor for Determining Formaldehyde in Indoor Air." Lawrence Berkeley Laboratory Report No. LBL-12560. Presented at the International Symposium on Indoor Air Pollution, Health and Energy Conservation, Amherst, Massachusetts, October 13-16, 1981.
3. National Institute for Occupational Safety and Health. Manual of Analytical Methods. 2d ed. 1:125-1 to 125-9.

Operations experience

1. None available

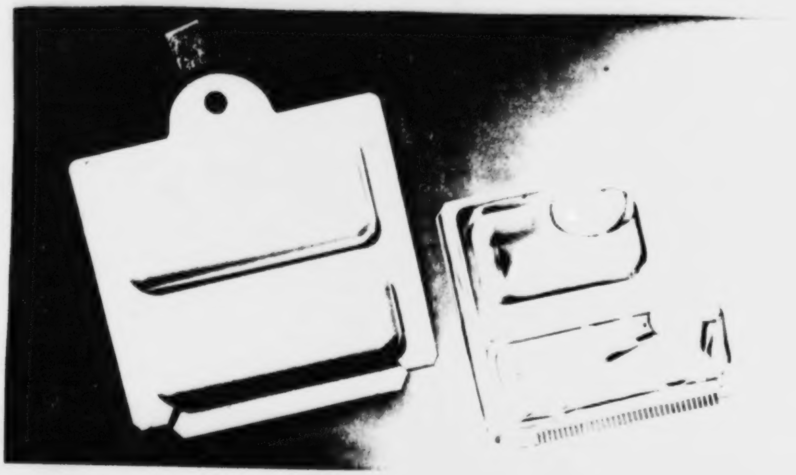
Remarks: These devices do not require specialized training for use. However, extreme care must be exercised in proper placement in the field and recordation of the exposure interval. The units should be exposed at least in immediate pairs at each sampling point. Therefore, a simple indoor/outdoor comparison, for instance, would require four samplers.

Though not yet formally validated under field conditions, the sampler is coming into extensive use. The Canadian government is using the device in an extensive ongoing study examining formaldehyde levels in several tens of thousands of homes with urea formaldehyde foam insulation. Published results were unavailable at press time.

Shelf life of the PF-1 has been validated for at least 2 months.

4-2
DU PONT
PRO-TEK
HCHO passive
dosimeter
Type C60
1 of 4

FORMALDEHYDE
PERSONAL/PASSIVE/COLLECTOR



Weight: 17.8 g

Dimensions: 7.6 x 7.1 x 0.89 cm

Principle of Operation:	Sorption/colorimetry. Collection relies on molecular diffusion to deliver sample air to a liquid sorbent solution at a constant rate. After exposure, the sorbent is analyzed in a laboratory spectrophotometer for formaldehyde content and the time-weighted average concentration. A maximum exposure time has not been defined, although laboratory validation exposure times varied from 2 to 18 hours. The shelf life of exposed badges is 2 weeks, suggesting this to be a maximum exposure time.
Lower Detectable Limit:	1.6 ppm-hr (0.010 ppm for 1-week exposure).
Range:	1.6 to 54 ppm-hr.
Interferences:	Free of interferences from n-butanol, ethanol, toluene, and phenol.

Multiparameter Capability: HCHO only

Performance:

Sampling Rate: diffusion, continuous

Accuracy: ±13.1% (overall system accuracy) over the range of 1.6 to 54 ppm hrs.

Precision: 5.9%

Reproducibility:

Linearity:

Noise:

Lagtime:

Rise Time: 2.6 seconds (calculated)

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: 4° to 49° C

Temperature Compensation:

Relative Humidity Range:

Calibration: laboratory standards

Unattended Period: 2 to 18 hours

Maintenance:

Power: none required for sampling

Features: Output:

Training: see remark #2

Options:

Costs: Type C60, 10 per box:

1-10 boxes: $222 (Order Code 5147)
11-25 boxes: $201 (Order Code 5148)
26+ boxes: $160 (Order Code 5149)

Manufacturer: E.I. Du Pont de Nemours & Co. (Inc.)
Finishes and Fabricated Products Department
Applied Technology Division
Bailey Mill Plaza, Marshall Mill Building
Wilmington, Delaware 19898

(302) 772-5989

References: Specifications

1. Manufacturer's sampling and analytical procedure.
2. Kring, E.V., et al. "A New Passive Colorimetric Air Monitoring Badge for Sampling Formaldehyde in Air." Submitted to Am. Ind. Hyg. Assoc. J. for publication.

Operations experience

1. None available

Remarks:

Each badge carries two compartments of sorbant solution--one for sampling, the other (thoroughly sealed until analysis) acts as a blank.

Du Pont does not plan to market this device directly to homeowners because of the absence of professional supervision to ensure accuracy for sampling results.

An analytical service for exposed badges is available from a number of AIHA-accredited laboratories.

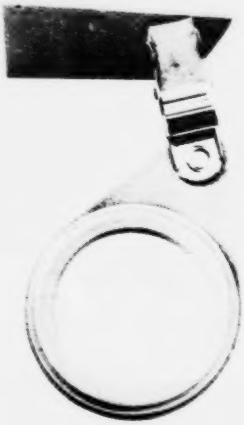
Shelf life of the dosimeter is as follows:

Unexposed: 6 months refrigerated (40° to 45° F),
3 months unrefrigerated (up to 78° F)

Exposed: 2 weeks refrigerated, 2 weeks unrefrigerated.

4-3
3M
Formaldehyde Monitor 3750
1 of 3

FORMALDEHYDE
PERSONAL/PASSIVE/COLLECTOR



Weight:

Dimensions:

Principle of Operation:	Sorption/spectrophotometry. Formaldehyde diffuses into the monitor and is collected by a chemisorption process onto an impregnated media. At a constant sampling rate, the amount of formaldehyde adsorbed is controlled by concentration and exposure time. At the end of sampling, the monitor is sealed and taken to the laboratory where collected formaldehyde is desorbed using water and quantitated spectrophotometrically. The weight of received formaldehyde is linearly related to the time-weighted-average exposure.
Lower Detectable Limit:	0.8 ppm-hr (0.005 ppm for 1-week exposure)
Range:	Up to 72 ppm-hr
Interferences:	Phenol, alcohols, and unsaturated compounds at 10 to 20 times the formaldehyde concentration

Multiparameter Capability: HCHO only

Collection Efficiency: 1.00 ±0.04

Performance:

Sampling Rate: 65.9 ±2.1 ml/min or 4.88 μg/ppm-hr, continuous

Accuracy: <±25%; exceeds OSHA accuracy requirements

Reproducibility:

Linearity:

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: -20° to 130° F

Temperature Compensation: none required

Relative Humidity Range: 15% to 95%

Calibration: laboratory standards

Unattended Period: up to 1 week

Power: none required for sampling

Features:

Output: laboratory report

Training: none required for sampling

Options:

Costs:

3750 (sampler plus analysis at 3M): $35
3751 (sampler only): $21

Manufacturer:

Occupational Health and Safety Products Division/3M
220-7W, 3M Center
St. Paul, Minnesota 55144

(612) 733-6234

References:

Specifications

1. Manufacturer's brochure
2. Rodriguez, S.T., P.B. Olsen, and V.R. Lund. "Colorimetric Analysis of Formaldehyde Collected on a Diffusional Monitor." Technical bulletin R-AIHA5(71.1)R, 3M Company, St. Paul, Minnesota.

Operations experience

1. None available

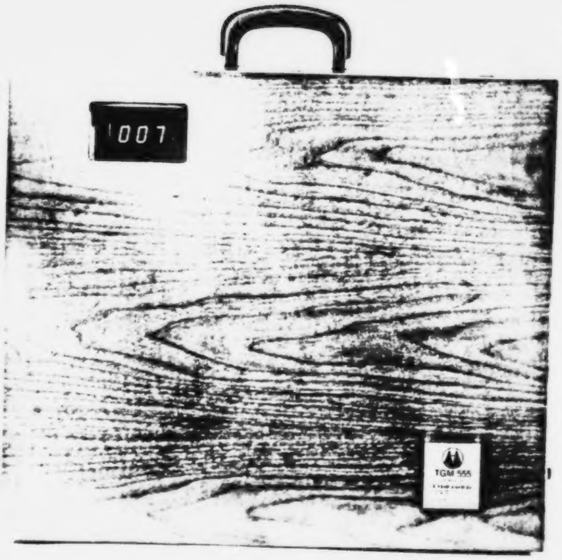
Remarks:

Shelf life for the Formaldehyde Monitor is as follows:

Unexposed: 1 year at room temperature
Exposed: 4 weeks at room temperature

FORMALDEHYDE
PORTABLE/ACTIVE/ANALYZER

4-4
TGM 555
FORMALDEHYDE ANALYZER
1 of 3



Weight: 14 kg

Dimensions: 51 x 41 x 18 cm

Principle of Operation:	Automated wet chemistry/colorimetry. Sample air is drawn through a sodium tetrachloromercurate solution that contains a fixed quantity of sodium sulfite. Acid bleached pararosaniline is added, and the intensity of the resultant color is measured at 550 nm. Reagent handling and processing is automatic.
Lower Detectable Limit:	0.002 ppm
Range:	0 to 5 ppm (with optional stream splitter range can be multiplied by a factor of 10 or 100); adjustable from 0 to 0.15 ppm full scale
Interferences:	None

Multiparameter Capability:	Collection Efficiency: 98%
Performance:	Sampling Rate: 500 ml/min, continuous
	Accuracy: ±3% (referenced to Chromotropic Acid Procedure)
	Reproducibility: 1%
	Linearity: <2% up to 3 ppm
	Noise: ±0.2% (zero noise)
	Lagtime: 4.5 minutes
	Rise Time: 4 minutes to 90%
	Retention Time:
	Fall Time: 4 minutes to 90%
	Zero Drift: <2% in 24 hours
	Span Drift: <2% in 24 hours
	Air Flow Drift: <1% in 24 hours
Operation:	Temperature Range: 60° to 80° F optimum; 40° to 120° F usable
	Relative Humidity Range: 5% to 95%
	Calibration: with liquid standards or HCHO permeation tubes
	Warm-Up Time: 20 minutes

Unattended Period: 18 hours on fully charged batteries

Maintenance: pump tubes changed once a month

Power: 12 V d.c. unregulated, 4 watts
115/230 V a.c., 50/60 Hz

Features:

Output: digital panel meter
0 to 1 V at 0 to 2.0 ma recorder output

Training: none required for sampling

Options: stream splitter (to multiply range)

Costs:

TGM 555: $5,410

Stream Splitter: $295

Manufacturer:

CEA Instruments, Inc.
15 Charles Street
Westwood, New Jersey 07675

(201) 664-2300

References:

Specifications

1. Manufacturer's bulletin

Operations experience

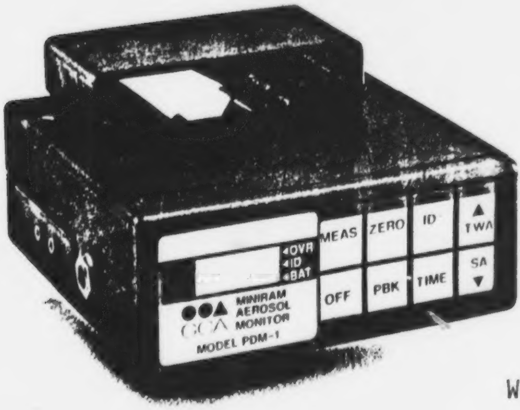
1. Matthews, T.E., and T.C. Howell. 1981. "Visual Colorimetric Formaldehyde Screening Analysis for Indoor Air." J. Air Pollut. Control Assoc. 31:1181-84.

Remarks:

A new calibration gas generator, the SC-100 which operates at 100° C using HCHO permeation tubes, is now available for dynamic gaseous calibration of the TGM 555.

INHALABLE PARTICULATE MATTER
PERSONAL/PASSIVE/ANALYZER

5-1
GCA MINIRAM
Aerosol Monitor
1 of 4


MEAS
ZERO
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PBK
TIME
◂OVR
◂ID
◂BAT
GCA
MINIRAM AEROSOL MONITOR
MODEL PDM-1

Weight: 0.4 kg

Dimensions: 10 x 10 x 4 cm

Principle of Operation:	Optical Scattering. Sample air passes through the open sensing volume by free convection. A pulsed near-infrared emitting diode, in combination with a silicon detector with an interference filter, senses forward light scattering (centered at 70° ±25°).
Lower Detectable Limit:	Scattering coefficient of approximately $10^{-5}m^{-1}$ (mass equivalence is tied to reference dust)
Range:	0.01 to 100 mg/m^3 (auto-ranging 0-10, 0-100)
Interferences:	Extreme ambient light fluctuations
Multiparameter Capability:	Particulate matter, liquid or solid readings only

Performance:

Sampling Rate: open convection, continuous

Accuracy: if calibrated for specific aerosol, equal to reproducibility

Reproducibility:

±0.05 mg/m^3 for 10-second measurement
±0.02 mg/m^3 for 1-minute average
±0.006 mg/m^3 for 10-minutes average
±0.003 mg/m^3 for 1-hour average

Linearity:

Noise: ±0.05 mg/m^3 for 10 second measurement

Lagtime: digital readout, 10 seconds
analog output, 0.5 seconds

Rise time: digital readout, 10 seconds
analog output time constant, 0.2 seconds

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: 0° to 50° C

Temperature Compensation: electronic

Relative Humidity Range: 0% to 95%

Calibration: automatic zero reference in clean environment, optional reference scatterer, or gravimetric reference calibration

Warm-Up Time: 1 minute

Unattended Period: at least 8.5 hours with battery

Maintenance: occasional cleaning or replacement of slide-in sensing chamber

Power: internal rechargeable 7.5-volt battery; charger operates from a.c. line

Features:

Output: 3-digit LCD (updated every 10 seconds)
0- to 2-volt analog recorder output; digital

Training: none required for sampling

Options: miniature strip chart recorder, zero check filter air unit, personal filter sample adaptor, respirator/face mask monitoring adaptor, shoulder strap, table stand, extra battery pack

Costs:

MINIRAM: $1,445 (includes charger/a.c. line adaptor, instrument/accessory case, manual)
Recorder: $1,170
Personal sampler adaptor: $250
Respirator adaptor: $150
Zero check unit: $260
Shoulder strap: $25
Table stand: $25

Manufacturer:

GCA Corporation
Technology Division, Environmental Instruments
213 Burlington Road
Bedford Massachusetts 01730

(617) 275-5444

References: Specifications

1. Manufacturer's bulletin
2. P. Lilienfeld. 1982. Final Report to the Bureau of Mines on Contract No. H0308132.
3. P. Lilienfeld. "Current Mine Dust Monitoring Instrumentation Developments." Proceedings of the 1981 International Symposium on Aerosols in the Mining and Industrial Work Environment. To be published in 1983.

Operations experience

1. None available

Remarks: The unit comes with a factory calibration based on a representative test dust. An internal control allows adjustment of response to match any reference gravimetric calibration.

The GCA MINIRAM offers the following data handling capabilities:

Readouts: selectable; 10-second measurements; time-averaged measurements; shift-averaged measurements; elapsed sampling time

Storage: 7 average concentrations, sampling times, off-times, and sampler identification number

Memory playback: either through instrument's own LCD or by 300-baud ASCII (20 mA loop or RS232 may be connected with proper interface)

INHALABLE PARTICULATE MATTER
PORTABLE/ACTIVE/ANALYZER

5-2
GCA RAM-1
Aerosol Monitor
1 of 4

Weight: 4 kg

Dimensions: 20 x 20 x 20 cm

Principle of Operation: Optical Scattering. As sample air, drawn by pump, passes through the sensing volume, a pulsed near-infrared emitting diode in combination with a silicon detector senses forward light scattering (centered at 70° ±25°). The upper limit of the particle size range is 20 μm; a series of precollectors offer cutpoints of 1, 2, 4, and 8 μm.

Lower Detectable Limit: Scattering coefficient of approximately 4×10^{-6} m^{-1} (mass equivalence is tied to reference dust)

Range: 0.001 to 200 mg/m^3 (selectable 0 to 2, 0 to 20, or 0 to 200)

Interferences: None

Multiparameter Capability: Particulate (liquid or solid) matter readings only

Performance:

Sampling Rate: 2 l/min (adjustable 1 to 3 l/min), continuous

Accuracy: if calibrated for specific aerosol, equal to precision

Reproducibility: ±0.1% FS or ±0.005 mg/m^3 (whichever is larger)

Linearity: 1% or better

Noise: ±0.001 mg/m^3 at 32-second time constant
±0.005 mg/m^3 at 2-second time constant

Lagtime: <0.5%

Rise Time: equal to time constant (selectable time constants of 0.5, 2, 8, and 32 seconds)

Retention Time:

Fall Time: equal to time constant (selectable time constants of 0.5, 2, 8, and 32 seconds)

Zero Drift: ±0.1% or ±0.005 mg/m^3

Span Drift determined by measurement and zero precision stability over 24 hours (whichever is larger)

Operation:

Temperature Range: 0° to 50°C

Temperature Compensation: electronic

Relative Humidity Range: 0% to 95%

Calibration: reference scatterer or gravimetric reference calibration

Warm-Up Time: <1 second

Unattended Period: at least 6 hours on battery, unlimited on charger

Maintenance: refillable diffusion-type drying cartridge for use in condensing atmospheres; high capacity filter cartridges externally accessible

Requirements:

Power: Internal rechargeable 6-volt battery; charger operates from a.c. line

Features:

Output: 4-digit LCD (updated 3 times each second); 0- to 10-volt a.c. recorder output (minimum load impedance: 1,000 ohms)

Training: none required for sampling

Options: miniature strip chart recorder; intrinsic safety version available; averager/integrator

Costs:

RAM-1: $5,950 (includes charger/a.c. line adaptor, charger cable, cyclone preselector, inlet flow restrictor, two replacement filter cartridges, refillable desiccator, carrying strap, instrument/accessory case, manual)
Recorder: $1,170
Intrinsic safety version: $6,550
Averager/integrator: $1,490

Manufacturer:

GCA Corporation, Technology Division,
Environmental Instruments
213 Burlington Road
Bedford, Massachusetts 01730

(617) 275-5444

References:

Specifications

1. Manufacturer's bulletin, #2-80 CP/5M
2. Tomb, T.F., H.N. Treaftis, and A.J. Gero. 1981. "Instantaneous Dust Exposure Monitors." *Environ. Int.* 5:85-96.

Operations experience

1. Chansky, S.H., P. Lilienfeld, and K. Wiltsee. 1979. *Evaluation of GCA Corporation's Model RAM-S as an Equivalent Alternative to the Vertical Elutriator for Cotton Dust Measurement.* Natural Fibers Textile Conference, Charlotte, North Carolina.
2. Konishi, Y., *An Evaluation of RAM-1 (GCA).* Working Environment Research Division of Kitasato Health Science Center, Japan.
3. Rubow, K.L., and V.A. Marple. 1981. *An Instrument Evaluation Chamber.* C Liberation of Commercial Photometers, Extended Abstracts and Final Program. International Symposium on Aerosols in the Mining and Industrial Work Environment, November 1-6, 1979, Minneapolis, Minnesota.
4. Taylor, C.D., and R.A. Jankowski. 1981. *The Use of Instantaneous Samplers to Evaluate the Effectiveness of Respirable Dust Control Methods in Underground Mines.* Extended Abstracts and Final Program, International Symposium on Aerosols in the Mining and Industrial Work Environment, November 1-6, 1981, Minneapolis, Minnesota.

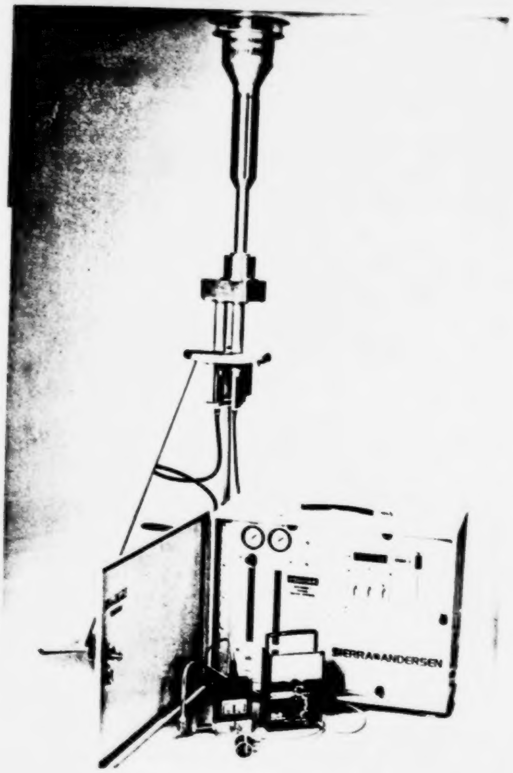
Remarks:

The unit comes with a factory calibration attuned to a representative respirable test dust. A panel-mounted control allows precise adjustment of response to match any reference gravimetric calibration.

The unit can be incorporated into a multipoint sensing approach with central data acquisition. Model RAM-S is specifically designed for such applications.

INHALABLE PARTICULATE MATTER
STATIONARY/ACTIVE/COLLECTOR

5-3
SIERRA-ANDERSEN
Dichotomous Sampler
Series 241
1 of 4



Net
Weight: Control Module, 25 kg
Sampling Module, 7 kg

Total Shipping Weight: 39 kg

Dimensions:
Control Module, 41 x 56 x 28 cm
Sampling Module, 162 cm height, 76.2 cm diameter tripod base bolt circle; interconnecting tubing, 10 m long

Principle of Operation:	Size-selective inlet followed by virtual impactor. Ambient air first is accelerated through a nozzle/target impactor to remove particles larger than 10 μm aerodynamic diameter. The sample air (containing particles <10 μm)) then passes through a virtual impactor that has a cut point of 2.5 m. Fine (<2.5 μm) and coarse (>2.5 μm) fractions are collected, on separate 37-mm TEF-DISC™ Teflon filters. Mass concentration is quantitated gravimetrically.
Lower Detectable Limit:	
Range:	Any ambient particulate concentration
Interferences:	The Teflon filters have zero artifact formation.

Multiparameter Capability: Fine (<2.5 μm) and coarse (2.5-10 μm) fractions and inhalable particulate matter (fine + coarse)

Performance:

Sampling Rate: total sample flow: 16.7 l/min
fine fraction: 15 l/min
coarse fraction: 1.67 l/min

Accuracy: constant flow controller: ±5% at 16.7 l/min
over pressure drop range: 0-35 cm Hg
standard timer: ±30 minutes per 7 days
optional timer: ±2 minutes per week
flow meters: ±3% at set flows

Reproducibility: ±5%

Linearity:

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: -20° to 40° C

Temperature Compensation:

Relative Humidity Range: 0% to 100%

Calibration: only flow calibration required

Procedure:

Warm-Up Time:

Unattended Period: defined by sampling schedule

Maintenance: routine

Power: 110/115 V a.c. ±10%, 50 to 60 Hz, 6 amp max;
230 V a.c. ±10%, 50 Hz, 4 amp max (optional)

Features:

Output: elapsed timer: 0 to 10,000 minutes in tenths
flow event circular chart: 24 hours, 10 cm diameter
vacuum gages: 0 to 30 inches of Hg

Training: recommended

Options: digital timer/programmer

Costs:

Series 241 dichotomous sampler: $4,675
Digital timer/programmer: $300
Model 246-10 field modifications kit (to retrofit 15 μm dichotomous samplers): $875

Manufacturer:

West Coast

Sierra-Andersen
P.O. Box 909
Carmel Valley, California 93924

Toll-free: (800) 538-9520
In California:
(408) 659-3177

East Coast

Sierra-Andersen
4215 Wendell Drive
Atlanta, Georgia 30336

Toll-free: (800) 241-6898
In Georgia:
(404) 691-1910

References:

Specifications

1. Manufacturer's bulletin, No. SA-PM10-682

Operations experience

1. None available

Remarks:

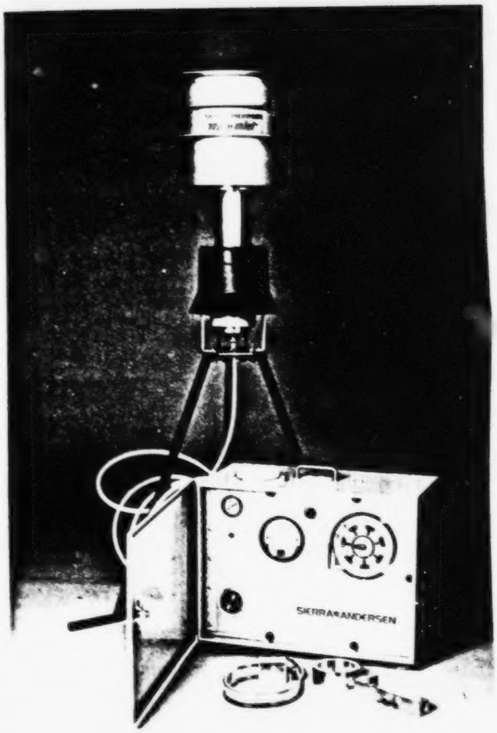
The size selective inlet has a cut point at 10 ±1 μm over wind 2-24 KPH; the virtual impactor has a cut-point at 2.5 μm; internal losses of the virtual impactor are less than 2% of 0 to 10 μm size range

The manufacturer also offers a field modification kit (model 246-10) to retrofit existing 15 μm samplers for 10 μm performance.

If EPA promulgates a 10 μm particulate matter standard, the manufacturer guarantees to obtain EPA reference method approval for this instrument and further guarantees that the model 246-10 inlet to retrofit existing 15 μm samplers will meet EPA performance specifications.

INHALABLE PARTICULATE MATTER
STATIONARY/ACTIVE/COLLECTOR

5-4
SIERRA-ANDERSEN
Medium Flow Samplers
Series 254
1 of 4



Net
Weight: Control Module, 27 kg
Sampling Module, 11 kg

Total Shipping Weight: 43 kg

Dimensions:
Control Module, 41 x 56 x 28 cm;
Sampling Module, 134 cm height;
Aerosol Inlet, 1.3 m height;
six 1/4 in-20 mounting bolts on 91.4 and 101.6 cm diameter bolt circles; interconnecting tubing, 5 m long

Principle of Operation: Suspended particles in ambient air enter the 10 μm Med-Flo™ inlet at a flow rate of 6.8 m^3/hr. The particles are then accelerated through multiple impactor nozzles. By virtue of their larger momentum, particles greater than the 10 μm cut point impact out and are retained in the impaction chamber. The particle fraction smaller then 10 μm is carried vertically upward by the air flow and down the vent tube to the 1-2 mm Sierra-Andersen TEF-DISC™ Teflon filter where it is uniformly collected.

Lower Detectable Range:	
Range:	Any ambient particulate concentration
Interferences:	Teflon filters have zero artifact formation
Multiparameter Capability:	Inhalable particulate matter <10 μm only
Performance:	Sampling Rate: 6.8 m^3/hr
	Accuracy: Pneumatic flow controller, ±5% accuracy of 6.8 m^3/hr over an inlet pressure drop of 0 to 25 cm Hg; ±10% over an inlet pressure drop of 0 to 30 cm Hg
	Reproducibility: ±3%
	Linearity:
	Noise:
	Lagtime:
	Rise Time:
	Retention Time:
	Fall Time:
	Zero Drift:
	Span Drift:

Operation:

Temperature Range: -20° to 40° C, 600 to 800 mm Hg

Temperature Compensation:

Relative Humidity Range: 0% to 100%

Calibration: only flow calibration required

Warm-Up Time: N/A

Unattended Period: defined by sampling schedule

Maintenance: routine

Power: 254, 254M: 110/115 V a.c., 50 to 60 Hz, 7 amp max;
254X, 254MX: 220 V a.c., 50 Hz, 4 amp max

Features:

Output: flow event circular chart, 24 hours
magnehelic gauge flow indicator

Training: recommended

Options: digital timer/programmer (optional), all functions digital and quartz crystal controlled; has digital clock with 1/2-inch LED

Costs:

Series 254 Medium Flow Sampler: $3,475
Series 302 Digital Timer/Programmer: $300

Manufacturer:

West Coast

Sierra-Andersen
P.O. Box 909
Carmel Valley, California 93924

Toll-free: (800) 538-9520
In California:
(408) 659-3177

East Coast

Sierra-Andersen
4215 Wendell Drive
Atlanta, Georgia 30336

Toll-free: (800) 241-6898
In Georgia:
(404) 691-1910

References: Specifications

1. Manufacturer's bulletin, No. SA-PM10-682

Operations experience

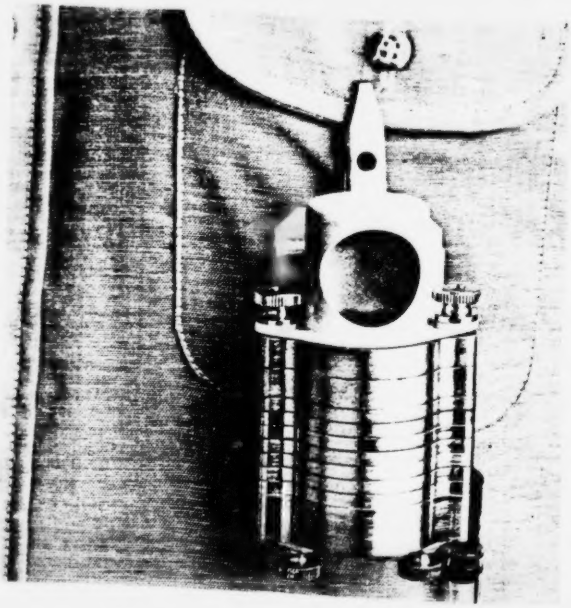
1. None available

Remarks: The size-selective inlet has a cut point at 10 ±1 µm over wind speed of 2 to 24 KPH; it meets EPA's expected PM_{10} Federal Reference Method.

If EPA promulgates a 10 µm particulate matter standard, the manufacturer guarantees to obtain EPA Reference Method approval for this instrument.

INHALABLE PARTICULATE MATTER
PERSONAL/ACTIVE/COLLECTOR

5-5
SIERRA INSTRUMENTS
MARPLE PERSONAL
CASCADE IMPACTOR
1 of 4



Model:	294	296	298	
Weight:	170	185	200	g
Dimensions:	7.2	8.0	8.6	height
	5.7	5.7	5.7	width
	4.0	4.0	4.0	depth

Principle of Operation: Impaction. Upon entering the inlet, sample air is accelerated through radial slots in the first impaction stage. Particles larger than the cut point impact on the perforated collection substrate. The sample air stream then passes to the next impactor stage, which exhibits a smaller cut point for impaction, and so on through successively smaller cut points; remaining fine particles are collected on a backup filter. The model 294 has four stages, the model 296 has six stages, and the model 298 has eight stages.

Lower Detectable Limit:

Range: Model 294 (4 stages)--cut points at 21, 15, 10, and 3.5 μm
Model 286 (6 stages)--cut points at 10, 6, 3.5, 1.6, 0.9, and 0.5 μm
Model 296 (8 stages)--cut points at 21, 15, 10, 6, 3.5, 1.6, 0.9, and 0.5 μm

Interferences:

Multiparameter Capability:

Performance:

Sampling Rate: 2 l/min

Accuracy:

Reproducibility:

Linearity:

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range:

Temperature Compensation:

Relative Humidity Range:

Calibration:

Procedure:

Warm-Up Time:

Unattended Period:

Maintenance:

Power:

Features:

Output:

Training:

Options:

Costs:

Model 294: $775
Model 296: $975
Model 298: $1,175

Manufacturer:

Sierra Instruments, Inc.
P.O. Box 909
Carmel Valley, California 93924

Toll free: (800) 538-9520

In California: (408) 659-3177

References: Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks: Available time did not permit review of this summary by a manufacturer's representative. Pricing information was verified by telephone.

INHALABLE PARTICULATE MATTER
PORTABLE/ACTIVE/ANALYZER
STATIONARY/ACTIVE/ANALYZER

5-6
TSI Piezo Balance
Model 3500 and
Model 5000
1 of 5

Weight: 4.5 kg (Model 3500); 48 kg (Model 5000)

Dimensions: 31 x 13 x 17 cm, Model 3500
38 x 43 x 18 cm, sensor module
38 x 43 x 18 cm, control module
38 x 43 x 42 cm, reservoir module
} Model 5000

Principle of Operation: Electrostatic precipitation/piezoelectric resonance. The sample air stream is passed through a cyclone or an impactor to remove nonrespirable particles (aerodynamic diameter >3.5 μm). RSP aerosol exiting the impactor is electrostatically precipitated onto a quartz crystal sensor. The change in oscillating frequency of the sensing crystal during the measurement period is proportional to collected mass. The Model 3500 is battery-powered and portable with manually initiated sampling periods. The Model 5000 is not battery-powered, but has programmable automatic sampling cycles for 24-hr/day monitoring.

Lower Detectable Limit: Approximately 5 μg/m^3 over a 10-minute averaging time

Range:

	Model 3500	Model 5000
Mass:	0.01 to 10 mg/m^3	0.005 to 9.999 mg/m^3
Size:	0.01 to 10 μm (50% cut off)	0.01 to 10 μm (50% cut off)

Interferences: Changes in relative humidity during a single measurement period can cause error. Dry, submicrometer, long-chain agglomerated particles with no condensed water and no other particles present (e.g., pure, dry diesel exhaust particles) are not sensed accurately.

Multiparameter Capability: RSP mass only

Performance:

Collection Periods: 24 to 120 seconds measurement period (Model 3500); 10 seconds to 2 hours measurement period (Model 5000)

Collection Efficiency: for respirable particles that have passed through the respirable cyclone or impactor, >95% of the particles between 0.05 and 5 μm deposit on the sensor

Sampling Rate: 1 l/min

Accuracy: ±10% ±0.01 mg/m^3

Reproducibility: ±5%

Linearity: ±10% for concentrations below 10 mg/m^3

Noise: ±1 μg/m^3 in most indoor environments

Lagtime: 1 to 2 seconds

Rise Time:

Retention Time:

Fall Time:

Zero Drift: automatic rezero at the beginning of every measurement

Span Drift: crystal sensitivity is an inherent property of the unbroken piezoelectric quartz crystal; span does not drift

Operation:

Temperature Range: 5° to 40° C

Temperature Compensation: none required if temperature remains constant within ±2° C during a single measurement period

Relative Humidity Range: 10% to 90%

Calibration: internal reference for both collection efficiency and crystal sensitivity

Procedure: portable, manual, panel control (Model 3500); programmable automatic control (Model 5000)

Warm-Up Time: in a normal room, 5 minutes or less (the instrument components in contact with the sample stream must be equilibrated within ±1° C of the sample stream temperature)

Unattended Period: 4 weeks (Model 5000)

Maintenance: clean sensor crystal after 5 μg accumulation, as indicated by display (Model 3500); check and refill liquid levels at 1- to 4-week intervals, refill paper tape (Model 5000); annual laboratory calibration recommended

Power: rechargable Ni-Cd, 8-hour operation at 50% duty cycle, 15 hours recharge needed (Model 3500) single phase a.c. at 500 watts total (Model 5000)

Features:

Output: 4-digit LED (both); 40-column dotmatrix on roll paper (Model 5000); both analog and digital outputs compatible with most data systems (Model 5000)

Training: none required for sampling

Options: variety of alternative upper size cut offs (impactors) ranging from 0.5-10 μm or respirable cyclone with 3.5 μm cutoff

Costs:

Model 3500: $4,990
Model 5000: $16,450

Manufacturer:

TSI, Incorporated
P.O. Box 43394
St. Paul, Minnesota 55164

(612) 483-0900
TELEX: 297-482

References:

Specifications

1. Manufacturer's bulletin, No. TSI 3500/5000-10/80-10M.
2. Sem, G., K. Tsurubayashi, and K. Homma. 1977. *Am. Ind. Hyg. Assoc. J.* 38:580-8.
3. Sem, G., and K. Tsurubayashi. 1975. *Am. Ind. Hyg. Assoc. J.* 36:791-800.
4. Sem, G., and P. Daley. 1979. *Aerosol Measurement.* D. Lundgren et al., ed. University Presses of Florida, Gainesville, Florida, pp. 672-85.
5. Sem, G., and F. Quant. 1982. *J. Aerosol Sci.* 13:227.
6. Sem, G., and F. Quant. 1982. *Aerosols in the Mining and Industrial Work Environment. Vol. 3, Instrumentation.* V. Parple and B. Liu, ed. Ann Arbor Sciences, Ann Arbor, Michigan.

Operations experience

1. Repace, J., and A. Lowrey. 1980. *Science*, 208:464.
2. Linch., A.L. 1981. *Evaluation of Ambient Air Quality by Personal Monitoring Volume II Aerosols, Monitor Pumps, Calibration, and Quality Control.* CRC Press, Inc., 2000 NW. 24th Street, Boca Raton, Florida.
3. Sem., G. 1977. National Bureau of Standards, Special Publication 464, pp. 191-7.

4. Fairchild, C., M. Tillery, and M. Ettinger. 1980. "An Evaluation of Fast Response Aerosol Mass Monitors." Report LA-8220. Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico.

5. Repace, J., and A. Lowery. 1982. *American Society of Heating, Refrigerating and Air-Conditioning Engineers Transactions*. Vol. 88, part 1.

6. Quant, F., P. Nelson, and G. Sem. 1982. "Experiental Measurements of Aerosol Concentrations in Offices." *Environ. Int.* 8:223-7.

7. Hersh, S., R. Fornes, and M. Anand. 1978. *Proceedings, 1978 Beltwide Cotton Production-Mechanization Conference and Special Sessions*. pp. 129-35. National Cotton Council of America, Memphis, Tennessee.

8. Hersh, S., R. Fornes, and M. Anand. 1979. *Am. Ind. Hyg. Assoc. J.* 40:578-87.

6-1
CSI 2200
Portable NO_x
Analyzer
1 of 4

NITROGEN DIOXIDE
PORTABLE/ACTIVE/ANALYZER

Weight: 8.7 kg

Dimensions: 20 x 1 x 46 cm

Principle of Operation:	Chemiluminescence. Sample air is initially routed to a reaction chamber where chemiluminescent reaction with ozone is detected and quantified by a photomultiplier tube, producing the NO signal, which is stored electronically. A second air sample is routed through an NO_2-to-NO converter and then to the ozone reaction chamber, producing the NO_x signal. The NO_2 value is electronically calculated by subtracting NO from NO_x.
Lower Detectable Limit:	0.020 ppm (5-second time constant setting) 0.010 ppm (60-second time constant setting)
Range:	0.5, 1.0, 2.0, or 5.0 ppm
Interferences:	Total interference equivalent for H_2O, SO_2, NO, and NH_3 is 0.10 ppm on the NO_x channel.

Multiparameter Capability: NO_x, NO, NO_2

Performance:

Sampling Rate: 700 ml/min, continuous

Accuracy: depends on calibration source accuracy

Reproducibility: 2% of full scale

Linearity: 1% for NO, NO_x; 1.5% for NO_2

Noise: 0.10 ppm at 5-second time constant, 0.005 ppm at 60-second time constant

Lag Time: 5 seconds at 5-second time constant and at 60-second time constant

Rise Time: 22 seconds at 5-second time constant; 3 minutes at 60-second time constant

Retention Time:

Fall Time: 20 seconds at 5-second time constant; 3 minutes at 60-second time constant

Zero Drift: ±0.005 ppm ±0.0005 ppm/° C at 15° to 35° C for 12 hours

Span Drift: ±2% ±0.3%/° C at 15 to 35° C for 12 hours

Operation:

Temperature Range: 10° to 40°C

Temperature Compensation: reactor and photomultiplier tube temperature controlled

Relative Humidity Range: 5% to 95%

Calibration: gas phase titration

Warm-Up Time: 30 minutes

Unattended Period: 2 hours on internal battery, 5 hours with external battery pack, 7 or more days with a.c. adapter/charger

Maintenance: converter life is normally 1 year; operating manual describes routine maintenance

Power: 12 V d.c.

Features:

Output: 0 to 1 V d.c. for NO, NO_x, NO_2; 12 V d.c. for optional battery-operated chart recorder, 10 V d.c., 1 mA-fault output, 10 V d.c., 1 mA-alarm output plus analog panel meter

Training: recommended

Options: portable recorder, 1-inch/hr chart speed 12-volt auto lighter cable assembly; auxillary battery pack (provides up to 8 hours of additional battery operation)

Costs:

Model 2200: $7,350

Recorder: $725

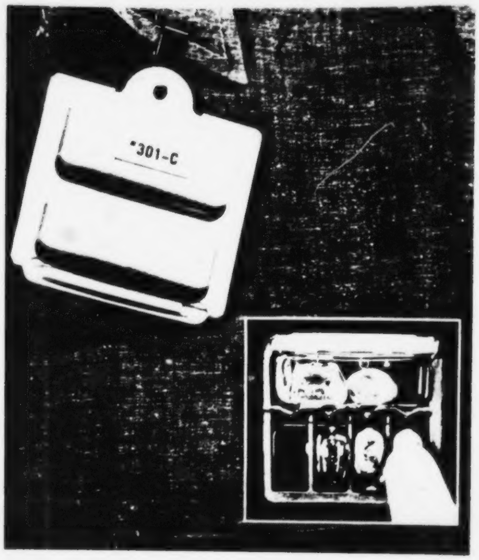
12-volt auto lighter cable: $98

Auxiliary battery pack: $575

Manufacturer:	Columbia Scientific Industries Corpor. P.O. Box 9908 Austin, Texas 78766 Toll-free: 800-531-5003 In Texas (512) 258-5191 TWX: 910-874-1364
References:	Specifications 1. Manufacturer's bulletin Operations experience 1. None available
Remarks:	Unit offers automatic failure diagnosis and display system. Photomultiplier tube temperature is maintained at 20° C by a thermoelectric cooling system to minimize noise and zero drift. Gas reaction chamber is regulated at 42° C to minimize span errors. CSI offers training sessions in Austin, Texas, on a monthly basis.

6-2
DU PONT
PRO-TEK^R
NO_2 Passive Dosimeter
Type C30
1 of 3

NITROGEN DIOXIDE
PERSONAL/PASSIVE/COLLECTOR



Weight: 16 g

Dimensions: 7.6 x 7.1 x 0.89 cm

Principle of Operation:	Diffusion/sorption. Collection relies upon molecular diffusion to deliver sample air to a liquid sorbent solution at a constant rate. After exposure, the sorbent is analyzed in a laboratory spectrophotometer or Pro-Tek^R PT-3 Readout for NO_2 content and subsequently the time-weighted average concentration. Laboratory validation has been conducted only for up to 8-hour exposures, although it is very likely that longer exposure times are possible.
Lower Detectable Limit:	10 ppm-hr, when analyzed in a PT-3 Readout; 1.5 ppm-hr, when analyzed in a laboratory spectrophotometer
Range:	10 to 100 ppm-hr (PT-3 Readout) 1.5 to 200 ppm-hr (laboratory spectrophotometer)
Interferences:	The major known interferences are SO_2, nitrates, ozone, and strong oxidizing agents. These interferences will not affect the Pro-Tek^R Sulfur Dioxide Colorimetric Badge for NO_2 because they have little or no affinity for the absorbing solution.

6-2
DU PONT
PRO-TEK^R
NO_2 Passive Dosimeter
Type C30
2 of 3

Multiparameter Capability: NO_2 only

Performance:

Sampling Rate: diffusion, continuous

Accuracy: ±18.2% (overall system accuracy)

Precision: 7.5%

Sensitivity: 1.5 ppm-hr

Response Time: 1.3 seconds (calculated)

Operation:

Temperature Range: 4° to 49° C

Temperature Compensation:

Relative Humidity Range:

Calibration: laboratory standards

Warm-Up Time:

Unattended Period: 8 hours

Maintenance: none

Power: none required for sampling

Features:

Output:

Training: none required for sampling

Options:

Costs:

Type C30, 10 per box:

1-10 boxes: @ $259 (Order Code 5115)
11-25 boxes: @ $233 (Order Code 5116)
26+ boxes: @ $207 (Order Code 5117)

Manufacturer:

E.I. du Pont de Nemours & Co. (Inc.)
Finishes and Fabricated Products Department
Applied Technology Division
BRML-9
Wilmington, Delaware 19898

(302) 772-5989

References:

Specifications

1. Manufacturer's analysis instructions.
2. Kring, E.V., et al. 1981. "A New Passive Colorimetric Air Monitoring Badge System for Ammonia, Sulfur Dioxide, and Nitrogen Dioxide." Am. Ind. Hyg. Assoc. J. 42:373-81.

Operations experience

1. Woebkenberg, M.L. 1982. "A Comparison of Three Passive Personal Sampling Methods for NO_2." Am. Ind. Hyg. Assoc. J. 43:553-61.
2. Laboratory Validation Report, Pro-Tek^R Nitrogen Dioxide Badge, Type C30, Du Pont (2/2/81).

Remarks:

Immediate readout is possible using PT-3 Colorimeter because chemical reagents are stored inside the badge. However, greater sensitivity is possible from a laboratory spectrophotometer.

Shelf life for the NO_2 Passive Dosimeter is defined as follows:

Unexposed - 6 months refrigerated (40° to 45° F)
Exposed - 3 weeks refrigerated (40° to 45° F)
2 weeks unrefigerated (up to 78° F)

NITROGEN DIOXIDE
PERSONAL/PASSIVE/COLLECTOR

6-3
MDA
Palmes Tube
1 of 3

Weight: 14 g

Dimensions: 8.9 cm length
1.3 cm diameter

Principle of Operation:	Diffusion/sorption. The sampler consists of a hollow tube with a permanently sealed base containing triethanolamine (TEA), an efficient collector for NO_2. The opposite end is fitted with a removable cap. During sampling, the cap is removed, and NO_2 diffuses to the collector at a rate determined primarily by the tube geometry and ambient NO_2 concentration. At the end of sampling, the cap is replaced. The TEA substrate is subsequently analyzed in the laboratory to quantitate the time weighted average concentration. Exposure periods in indoor air quality settings are ordinarily for 1 week or longer, while exposure periods in industrial hygiene applications are typically 8 hours.
Lower Detectable Limit:	1 ppm-hr
Range:	1 ppm-hr to 20 ppm-hr (ultimate sorbant capacity exceeds 1,000 ppm-hr)
Interferences:	None

Multiparameter Capability: May be user-converted to collect NO_x (see remark #2)

Performance:

Sampling Rate: approximately 1 nl/min at 1 ppm NO_2, continuous

Accuracy: ±20% at TLV

Reproducibility: ±10%

Operation:

Ambient Temperature Range: essentially unrestricted

Temperature Compensation: none required

Relative Humidity Range: 10% to 95%

Calibration: standard curve for laboratory analysis constructed by user from known standards

Unattended Period: 5 hours to 1 week

Power: none required for sampling

Features:

Output: laboratory report

Training: none required for sampling

Options:

Costs: $8.00 to $10.00 per tube (includes all necessary components except chemical reagents); detailed instruction manual accompanies package of 10 tubes describing all reagent preparation and analytical procedures

Manufacturer:

MDA Scientific, Inc.
1815 Elmdale Avenue
Glenview, Illinois 60025

(312) 998-1600

TELEX: 72-6399 MDA-GLVW

References:

Specifications

1. Manufacturer's bulletin
2. McMahon, R., Chemist, MDA Scientific, Inc. Personal communication, 1982.
3. Palmes, E.D. 1979. "Personal Sampler for Measurement of Ambient Levels of NO_2." Proceedings of the Symposium on the Development and Usage of Personal Monitors for Exposure and Health Effects Studies. U.S. Environmental Protection Agency Report No. EPA-600/9-79-032.
4. Palmes, E.D., and C. Tomczyk. 1979. "Personal Sampler for NO_x." Am. Ind. Hyg. Assoc. J. 40:588-59.

Operations experience

1. Palmes, E.D. 1981. " Development and Application of a Diffusional Sampler for NO_2." Environ. Int. 6:97-100.

Remarks:

Sampling range can be greatly extended by carefully diluting the desorbed sample.

The sampler can be converted to collect NO_x ($NO + NO_2$) by inserting a user-supplied oxidizing screen (see Palmes and Tomczyk 1979).

The sampler tubes are reusable.

NITROGEN DIOXIDE
PORTABLE/ACTIVE/ANALYZER

6-4
TGM 555
NO_2 ANALYZER
1 of 3

Weight: 14 kg

Dimensions: 51 x 41 x 18 cm

Principle of Operation:	Automated wet chemistry/colorimetry. Sample air is continuously absorbed in an azo dye forming reagent. The intensity of the azo dye formed is measured at 550 nm and is directly proportional to the concentration of NO_2. Reagent handling and processing is automatic.
Lower Detectable Limit:	0.005 ppm for 0 to 0.15 ppm full scale
Range:	0 to 0.15 ppm (adjustable to 10 ppm)
Interferences:	Negligible
Multiparameter Capability:	

Performance:

Sampling Rate: 250 ml/min, continuous

Accuracy:

Reproducibility: 1%

Linearity: <2% (up to 0 to 5 ppm range)

Noise:

Lagtime: 2 minutes

Rise Time: 3 minutes (to 90%)

Retention Time:

Fall Time: 3 minutes (to 90%)

Zero Drift: <2% (72 hours)

Span Drift: <2% (72 hours)

Operation:

Temperature Range: 15° to 25° C

Temperature Compensation:

Relative Humidity Range: 5% to 95%

Calibration: with liquid standards, permeation tubes, or gas-phase titration

Warm-Up Time: 20 minutes

Unattended Period: 18 hours on fully charged batteries

Maintenance:

Power: 12 V d.c. unregulated, 4 watts 115/230 V a.c., 50/60 Hz

Features:

Output: digital panel meter
0 to 1 V at 0 to 2.0 milliamps recorder output

Training: none required for sampling

Options: Reaction Chamber (for counting NO to NO_2)
Stream Splitter (to extend range by a factor of 10 or 100)

Costs:

TGM 555: $5,340

Reactor Chamber: $150

Stream Splitter: $295

Manufacturer:

CEA Instruments, Inc.
15 Charles Street
Westwood, New Jersey 07675

(201) 664-2300
TELEX: 642128

References:

Specifications

1. Manufacturer's bulletin

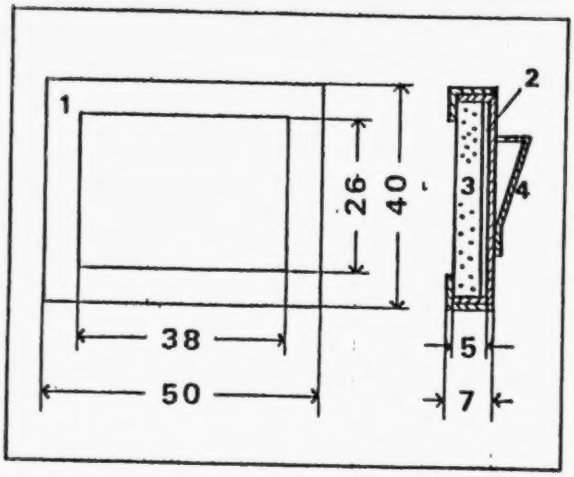
Operations experience

1. None available

Remarks:

The unit can be fitted for monitoring NO_x by installing a solid oxidant convertor, which converts NO to NO_2.

NITROGEN DIOXIDE
PERSONAL/PASSIVE/COLLECTOR



1 Badge case 2 Absorbent sheet
3 Diffision controlling mat 4 Clasp

Weight: 15 g

Dimensions: 5 x 4 x 1 cm

Principle of Operation:	Diffusion/adsorption. A filter treated with triethanolamine (TEA) adsorbs NO_2 that diffuses through a series of hydrophobic fiber filters that suppress wind effects. Sorbed NO_2 is quantitated spectrophotometrically.
Lower Detectable Limit:	66 ppb-hr
Range:	Up to 10^6 ppb-hr, theoretical
Interferences:	Adsorption rate for NO_2 may vary by as much as 20% under wind velocities between 0.15 and 4.0 m/sec. The effect of relative humidity (between 40% and 80% RH) is less than that of wind velocity. Maximum adsorption rate occurs at 60% RH.

Multiparameter Capability:	NO_2 only; may be converted to NO_x only (see remark #2)
Performance:	Sampling Rate: 1 ml/sec nominal, continuous
	Accuracy: ±20%
	Reproducibility: <4.8%
	Linearity: <1% (correlation of 0.99 under 24-hour test)
Operation:	Temperature Range: room temperature
	Temperature Compensation: unnecessary between 20° and 34° C
	Relative Humidity Range: 40% to 90%
	Calibration: standard curve for laboratory analysis constructed by user from known standards
	Unattended Period: 24 hours to 1 week; up to 1 month
	Maintenance:
	Power: none required for sampling
Features:	Output: laboratory report
	Training: none required for sampling
	Options:
Costs:	NO_2 filter badge: $11.65 each

Manufacturer:

Micro Filtration Systems
6800 Sierra Court
Dublin, California 94566

(415) 828-6010

References:

Specifications

1. Yanagisawa, Y., and H. Nishimura. 1980. "A Badge Type Personal Sampler for NO_2 to be Used in the Living Environment." Presented at the Fifth Clean Air Congress, Buenos Aires, Argentina, October 1980.
2. Yanagisawa, Y., and H. Nishimura. 1981. "Badge-Type Personal Sampler for Measurement of Personal Exposure to NO_2 and NO in Ambient Air." Presented at the International Symposium on Indoor Air Pollution, Health and Energy Conservation, Amherst, Massachusetts, October 1981.

Operations experience

1. Both references above summarize specifications as well as field use.

Remarks:

The badge can be converted for collecting NO_x ($NO + NO_2$) by treating intervening filters with a 5% chromium trioxide solution to oxidize NO to NO_2 as it diffuses to the sorbant filter. NO_2 diffuses through unaltered and is adsorbed.

Laboratory analysis is spectrophotometric and uses easily obtained reagents.

OZONE
PORTABLE/ACTIVE/ANALYZER

7-1
CSI 2000
PORTABLE OZONE METER
1 of 3

Weight: 7.7 kg (9.9 kg with optional battery pack)

Dimensions: 20.3 x 17.8 x 45.7 cm

Principle of Operation:	Chemiluminescence. Photometric detection of the flameless reaction of ethylene gas with ozone.
Lower Detectable Limit:	0.004 ppm (on 5-second filter setting) 0.001 ppm (on 60-second filter setting)
Range:	0 to 0.10, 0 to 0.20, 0 to 0.50, and 0 to 1.00 ppm
Interferences:	$<\pm 9.995$ ppm total for H_2O, CO, and H_2S
Multiparameter Capability:	Ozone only

Performance:

Sampling Rate: 700 ml/min, continuous

Accuracy:

Reproducibility: ±1.0% of full scale

Linearity: 1% of full scale

Noise: 0.002 ppm on 5-second filter setting, ±0.005 ppm on 60-second filter setting

Lagtime: 3 minutes

Rise Time: 15 seconds on 5-second filter setting
180 seconds on 60-second filter setting

Retention Time:

Fall Time: Same as rise time

Zero Drift: ±0.002 ppm ±0.0002 ppm/°C for 12 hours at 10° to 35° C

Span Drift: ±1% ±2%/°C for 12 hours at 10° to 35° C

Operation:

Temperature Range: 10° to 40° C

Temperature Compensation: none required, 10° to 40° C

Relative Humidity Range: 5% to 95%

Calibration: gas phase titration

Warm-Up Time: 30 minutes

Unattended Period: 8 hours for battery operation

Maintenance:

Power: 14 V d.c. (also 120 or 230 V a.c. with charger/adapter)

Features:

Output: panel meter, 0 to 1.0 or 0.100 mV recorder output

Training: recommended

Options: battery pack
battery charger

Costs:

Model 2000: $6,750 (includes battery and charger)

Manufacturer:

Columbia Scientific Industries Corp.
P.O. Box 9908
Austin, Texas

Toll free: (800) 531-5003

In Texas: (512) 258-5191

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

The Model 2000 is an EPA-Designated Reference Method for Ozone.

Not reviewed by manufacturer's representative. Pricing information has been verified by telephone.

8-1
AEROVIRONMENT (AV)
PRM LR-5
1 of 4

RADON
STATIONARY/PASSIVE/COLLECTOR

AEROVIRONMENT
EVEREADY

Weight: 9 kg

Dimensions: 51 mm high x 23 cm diameter

Principle of Operation: Electrostatic collection/thermoluminescent dosimetry. Ambient radon diffuses into a sensitive chamber where subsequent disintegration of ions are electrostatically focused onto a thermoluminescent dosimeter (TLD) chip held at negative potential in a 900 to 1200-volt electrostatic field. Each alpha particle striking the chip creates metastable defects in the crystal, which can be read and related to integrated radon concentration. A water-impermeable membrane keeps the chamber dry while allowing radon to diffuse in through the bottom. With the membrane, a desiccant material is not needed, greatly extending the possible sampling times in humid climates, and eliminating desiccant drying. A second TLD chip is exposed away from the electrostatic field (at the base of the housing) to check background levels of gamma radiation.

Lower Detectable Limit: Ranges from 0.03 pCi/l/week under laboratory conditions within a limited range of radon concentration to 0.2 pCi/l under adverse field conditions. (CaF_2:Dy TLD)

Range: 0.03 pCi/l to 10^4 pCi/l

Interferences:

Multiparameter Capability: Radon only

Performance: Sampling Rate: diffusion, continuous

Accuracy:

Reproducibility:

Linearity:

Noise:

Response time: 8 hours with mylar membrane

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Detector Response (CaF_2:Dy)--alpha 0.6 ±0.1 counts per pCi hr/l;
--gamma 16.5 counts per mR/hr

Operation: Ambient Temperature Range: -45° to 65° C

Temperature Compensation: none

Relative Humidity Range: 0% to 100% for extended periods

Calibration: laboratory calibration available

Warm-Up Time: none

Unattended Period: <1 week to 12 months

Maintenance: check battery voltage

Power: 4 Everready Mini-max No. 493 batteries

Features:

Output: counts from TLD reader

Training: none required for sampling

Options and Accessories: spare TLD holders
replacement batteries

Costs:

LR-5: $595 each (complete with batteries, good for 1 year); 2 TLD chip holders (more available on request); quantity discount available

Manufacturer:

AeroVironment, Inc.
5680 South Syracuse Circle #300
Englewood, Colorado 80111

(303) 771-3586

Head Office:

145 Vista Avenue
Pasadena, California 91107

References:

Specifications

1. Manufacturer's bulletin

2. George, A.C. 1977. "A Passive Environmental Radon Monitor." In Radon Workshop. A.J. Breslin, ed. U.S. Energy Research and Development Administration, Report HASL-325, Health and Safety Laboratory, New York, New York, pp. 25-30.

3. Friedland, S.S., L. Rathbun, and A.M. Goldstein. 1980. "Radon Monitoring: Uranium Mill Field Experience with a Passive Detector."

Operations experience

1. None available

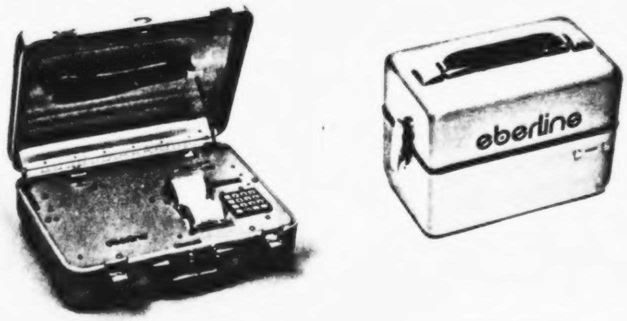
Remarks:

This instrument is based on the Passive Environmental Radon Monitor (PERM) developed at the DOE Environmental Measurements Laboratory (George 1977) and modified by AeroVironment (Freidland, Rathbun, and Goldstein 1980).

Recommended monitoring time for this instrument is 1 week to 1 month. However, nondesiccant membrane and spare battery voltage give exposure periods limited only by battery life, which should extend for at least 1 year.

8-2
EBERLINE
WORKING LEVEL MONITOR
1 of 3

RADON
STATIONARY/ACTIVE/COLLECTOR



Weight: 2.6 kg, WLM-1
6.8 kg, WLR-1

Dimensions: 14.6 x 11.7 x 20 cm, WLM-1
35.6 x 45.7 x 15.2 cm, WLR-1

Principle of Operation:	Filtration with integrated gross alpha counting. Radon progeny are collected on a filter and consequent alpha activity is measured using a silicon-diffused junction detector. A microprocessor counts and stores detected alpha pulses. The microprocessor also controls the sampling pump and records decay (tail) measurements after the sampling interval is terminated. Length of sample interval and detail of tail data are operator-selectable by key-pad entries on readout unit. Data are retrieved through a separate readout unit that also calculates working levels with percent thoron daughters.
Lower Detectable Limit:	2 x 10^{-5} WL (99% confidence level based on background of 0.1 counts per minute and 168 hours sample time)
Range:	Capable of measuring naturally occurring background levels with an upper limit as indicated below: Based on 200 1-minute intervals, 1.5 x 10^3 WL Based on 168 1-hour intervals, 1 x 10^2 WL
Interferences:	Cosmic radiation, long-lived alpha emitters such as uranium and thorium

Multiparameter Capability: Working level plus percent thoron daughters; detail of tail data

Performance:

Sampling Rate: 0.12 to 0.18 l/min, continuous; intervals are selectable

Accuracy: <5% maximum error under cases of extreme disequilibrium, plus any error induced by calibration. Typical accuracy is ±5%

Reproducibility: unknown, but expected to be very good

Linearity: ±0.5%

Noise: none

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift: none

Span Drift: none

Operation:

Ambient Temperature Range: 30° to 120° F

Temperature Compensation: none

Relative Humidity Range: 0% to 90% noncondensing

Calibration: americium or thorium alpha source along with flow rate calibration

Warm-Up Time: <1 min.

Unattended Period: 168-hour data run plus 4-hour tail acquisition with extended standby

Maintenance: Exchange sample filter; recharge battery

Power: 6-volt gel cell for sampler (6 amp-hour); a.c. power for readout

Features:

Output: (Readout unit) electrosensitive printer, 21 characters per line, 2 lines/sec, operator interactive alpha/numeric LCD display

Training: none required for sampling

Options: battery charging stations

Costs: Approx. $2,000 each, WLM-1; $3,000 each, WLR-1

Manufacturer:

Eberline Instrument Corporation
P.O. Box 2108
Santa Fe, New Mexico 87501

(505) 471-3232
TWX: (910) 985-0678

References:

Specifications

1. Beard, R., et al. 1981. "Eberline's New Microcomputer Based Radon Daughter Instrument." Presented at the International Symposium on Indoor Air Pollution, Health and Energy Conservation, Amherst, Massachusetts, October 1981.
2. Geiger, E.L. Eberline Instrument Corporation, personal communication, 1982.

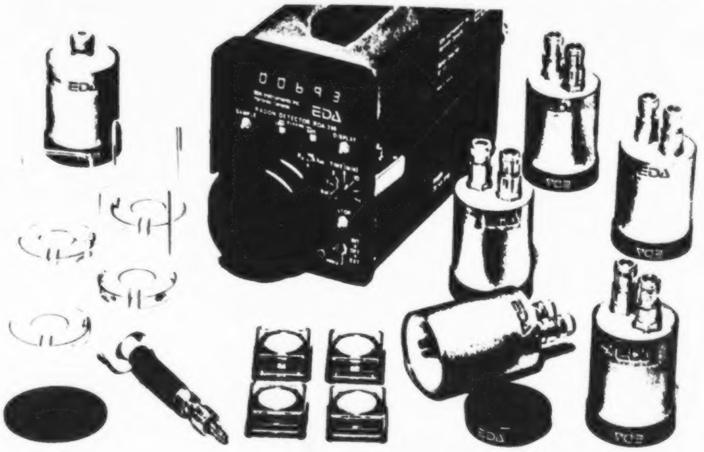
Operation experience

1. Prototypes have been tested at U.S. Bureau of Mines, Denver, CO. Further testing is planned and in progress.

Remarks: The readout unit (Model WLR-1) is required to service the monitor (Model WLM-1). One readout unit can service many WLM-1s.

8-3
EDA
RDA-200
Radon/Radon Daughter
Detector
1 of 4

RADON/RADON PROGENY PORTABLE/ACTIVE/ANALYZER



Weight: console, 1.7 kg; system, 8.0 kg

Dimensions: console, 12.7 x 16.5 x 20 cm
total system packaged, 61 x 61 x 35.5 cm
gas cell, 160 ml, 5.3 cm diameter x 7.3 cm

Principle of Operation: Scintillation coupled to a high gain photomultiplier and scaler. A known volume of sample air is drawn through a sampling train composed of a filter at the inlet followed by a gas scintillation cell and a user-supplied pump. Radon daughter products collect in the filter; the gas cell retains a sample of radon in air. The filter is placed in a scintillation tray for counting in the detector; the gas cell is placed directly into the detector for counting. Details of sampling (flow rate, duration) and subsequent alpha counting (time factors) are determined by the operator and the technique employed.

Lower Detectable Limit: Dictated by background and technique

Working Level: 0.03 Kusnetz
0.01 Tsivolglou
0.01 Rolle

Radon: subpicocurie/liter

Range:	0-99,999 counts (up to 15,000 cpm without loss of sensitivity); counting periods of 1, 2, 5, 10, and 60 minutes selectable plus manual
Interferences:	
Multiparameter Capability:	Working level, radon-222, thoron, radium-226
	Collection Efficiency:
Performance:	Sampling Rate: specified by user and technique
	Accuracy:
	Reproducibility:
	Linearity:
	Noise:
	Lagtime:
	Rise Time:
	Retention Time:
	Fall Time:
	Zero Drift:
	Span Drift
Operation:	Temperature Range: -30° to 40° C
	Temperature Compensation:
	Relative Humidity Range:

Calibration: radon-222 standard gas source and americium-241 disc

Warm-Up Time:

Unattended Period:

Maintenance:

Power: 8 C cells standard; external battery pack or a.c. line source optional

Features:

Output: 5-digit LED

Training: recommended

Options: RDU-200--degassing system for determinations from water and sediments
RDX-207--americium-241 calibration disc
RDX-261--battery charger
RDX-263--external a.c./d.c. converter
RDX-251--end of counting audio alarm
(Various air pumps, flow meters, and specialized detector cells also available)

Costs:

RDA-200: $4,450 (includes detector console, radium test cell, 5 double swagelock radon gas cells, 5 scintillator trays, 2 filter holders, 100 0.8 m filters, 8 C cell batteries and manual)
RDU-200: $1,950
RDX-207: $650
RDX-261: $250
RDX-263: $185
RDX-251: $75

Manufacturer:

EDA Instruments, Inc.
5151 Ward Road
Wheat Ridge, Colorado 80033

(303) 422-9122
TELEX: 450681

Head Office:
1 Thorncliffe Park Drive
Toronto, Canada M4H1G9
(416) 425-7800

TELEX: 06 23222 EDA TOR
Cables: INSTRUMENTS TORONTO

References:

Specifications

1. Manufacturer's bulletin, RDA-200 0189

Operations experience

1. Moschandreas, D.J., and H.E. Rector. 1981. "Indoor Radon Concentrations." International Symposium on Indoor Pollution, Health, and Energy Conservation, Amherst, Massachusetts.

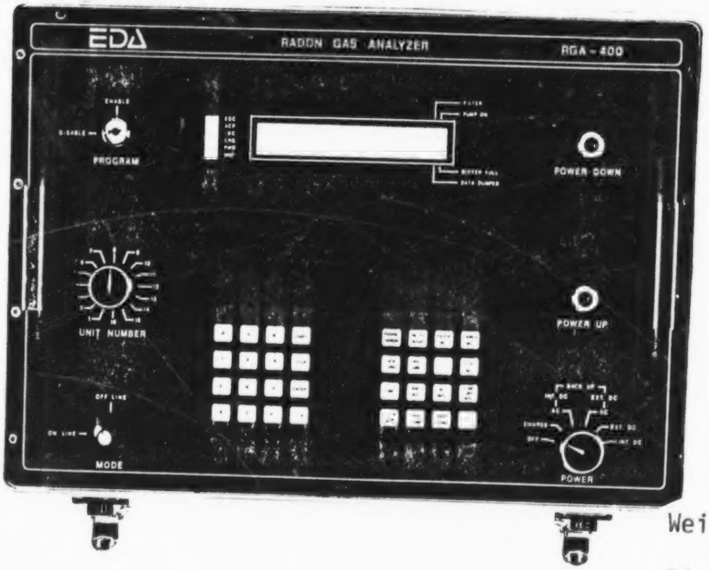
Remarks:

Manufacturer states that >1,000 instruments of this type are currently in use over 40 countries (manufacturer's bulletin).

Scintillator efficiency is in excess of 35% or 3.3 cpm/pci for the RDA-200.

8-4
EDA RGA-400
Radon Gas Monitor
1 of 4

RADON
STATIONARY/ACTIVE/ANALYZER



Weight:

Dimensions:

Principle of Operation:	Filtration/alpha spectroscopy and electrostatic precipitation with apex focusing collection/alpha spectroscopy. Ambient air is drawn through a prefilter, which collects daughter products of radon-222 and radon-220. Particle-free air enters a coaxially oriented 3000 ml sample chamber where decay ions are drawn by a strong electrostatic field to be deposited on a solid state detector. Subsequent alpha decay is spectrally analyzed to discriminate between the two radon isotopes. Daughter products captured on the prefilter are analyzed in a colinear detection system to discriminate all alpha-emitting daughters. Operation is controlled by a programmable microprocessor; all information is stored in a nonvolatile solid state memory for retrieval.
Lower Detectable Limit:	0.05 pci/l (gases); 0.002 WL (progeny)
Range:	0.0001 to 99.999 WL 0.01 to 99999 pci/l 0-99999 cpm

Interferences:

Multiparameter Capability: Radon-222, radon-220, polonium-218, polonium-214, polonium-216, bismuth-212, and polonium-212, plus working level

Collection Efficiency:

Performance:

Sampling Rate: 1 l/min, continuous; intervals are selectable

Accuracy: ±10%

Reproducibility: ≤5%

Linearity: ≥90%

Noise: ≤0.1 MWL

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift: no inherent drift

Span Drift: no inherent drift

Operation:

Temperature Range: -10° to 50° C

Temperature Compensation: none

Relative Humidity Range: 0% to 100%

Calibration: factory set, no field calibration required

Procedure:

Warm-Up Time:

Unattended Period: 2 weeks (498 data blocks at selected time intervals)

Maintenance:

Power: 110 V a.c., 60 Hz, internal rechargable standby batteries (up to 10 hours backup without data loss); external d.c. for extended remote applications; 220 V a.c., 50 Hz optional

Features:

Output: 64-character alpha-numeric LCD; optional thermal printer, magnetic cassette recorder or through CCU 500 central control unit; output is RS232 compatible

Training: none required for sampling

Options:
DCU-400 thermal printer
DCU-200 magnetic cassette tape recorder
CCU-500 central control unit
RGZ-401 major spare parts kit
WLX-341 filter cartridge (25 per pack)

Costs:

RGA-400: $15,900 (includes console, 25 filter cartridges, a.c. power cord, external d.c. power cord, minor spare parts kit, manual)
DCU-400: $2,750
DCU-200: $3,750
CCU-500: 12,500
RGZ-401: $35
WLX-341: $65

Manufacturer:

EDA Instruments, Inc.
5151 Ward Road
Wheat Ridge, Colorado 80033

(303) 422-9112
TELEX: 560681

Head Office:
1 Thorncliffe Park Drive
Toronto, Canada M4H1G9
(416) 425-7800

TELEX: 06 23222 EDA TOR
Cables: INSTRUMENTS TORONTO

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

The unit may be operated as a stand-alone monitor; or by using the CCU-500 central control unit. Distributed sampling networks can be formed with central data collection.

A high-quality humidity sensor has been incorporated to monitor the relative humidity level of the prefiltered ambient air. The data from the relative humidity sensor are used to compensate for variances in radon and thoron gas concentrations due to detector efficiency changes. The temperature of the prefiltered ambient air is measured, as well.

The following function/parameters are available:

Rn/Tn gas
Rn/TN ambient
PCL
Rn/Tn WL
INTGRWL

Alarm level max
Sample interval
Date time
Spectrum
Start data dump
Store data dump
Data recall

RADON
STATIONARY/ACTIVE/ANALYZER

EDA
WORKING LEVEL MONITOR
WLM-300

Weight: 6.8 kg

Dimensions: 342 x 304 x 350 mm

Principle of Operation:	Filtration/alpha detection. Radon daughter products are collected on a filter. Alpha activity is detected, averaged, and recorded. Working levels are recorded over periods of 1 hour (or 0.1 hour, selectable) for up to 41 days. Operation is controlled by an internal microprocessor.
Lower Detectable Limit:	0.0001 WL
Range:	0.0001 to 100 WL
Interferences:	

Multiparameter Capability:

Performance:

Sampling Rate: 1 l/min, continuous

Accuracy: ±10% (maximum deviation)

Reproducibility: ≤5%

Linearity: ≥90%

Noise: 0.0001 WL

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift: no inherent drift

Span Drift: no inherent drift

Operation:

Temperature Range: -10° to 50° C

Temperature Compensation: none

Relative Humidity Range: 0% to 100%

Calibration: factory set; no field calibration needed

Procedure:

Warm-Up Time:

Unattended Period: 41 days

Maintenance: The unit is designed for field operation in a typically hostile environment. Generally, it needs very little maintenance under normal operating conditions.

Power: 110 a.c., 60 Hz, internal rechargable or 9.5 to 14.0 V d.c. external; 220 a.c., 50 Hz optional

Features:

Output: 5-digit LCD; thermal printer, magnetic cassette recorder, and RS-232 I/O parts

Training: none required for sampling

Options:
DCU-400 thermal printer, a.c./d.c.
DCU-040 thermal printer
DCU-200 magnetic cassette tape recorder, a.c./d.c.
WLX-341 filter discs (25 per pack)
WLX-351 15 cm extension legs, set of 4
WLZ-301 major spare parts kit

Costs:

WLM-300: $6,550 (consists of console, 25 filter discs, a.c. power cord, minor spare parts kit, manual)
DCU-400: $2,750
DCU-040: $1,000
DCU-200: $3,750
WLX-341: $60
WLX-351: $45
WLX-301: $35

Manufacturer:

EDA Instruments, Inc.
5151 Ward Road
Wheat Ridge, Colorado 80033

(303) 422-9112
TELEX: 450681

Head Office:
1 Thorncliffe Park Drive
Toronto, Canada M4H169

TELEX: 06 23222 EDA TOR
Cables: INSTRUMENTS TORONTO

References:

Specifications

1. Manufacturer's bulletin, WLM-300-0291

Operations experience

1. None available

Remarks:

Mechanically, the WLM-300 is rugged and environmentally protected to permit operation in hostile outside environments. The unit is lightweight and is powered by line supplies for use in residential or inside industrial applications. For more remote sites, an external 9.5 to 14.0 V d.c. power may be used or the internal standby batteries may be used to fully operate the unit for up to 10 hours.

The WLM-300 is simplified by the internal microprocessor, and manual operations amount to replacing the prepackaged filter disc when it becomes loaded, initiating a sampling sequence, and extracting the data from memory. Calibration is unnecesary. The pump is feedback controlled to 1 l/m over the entire operating temperature range for up to 152 cm H_2O back pressures. The operator has full access to the last recorded results through the key pad and a liquid crystal display. Also a number of indicators act as a visual verification of keyed entries and system operation.

8-6
EDA
PERM
RDT-310
1 of 4

RADON
STATIONARY/PASSIVE/COLLECTOR

Weight: 4.5 kg

Dimensions: 250 mm diameter x 350 mm

Principle of Operation: Electrostatic collection/thermoluminescent dosimetry. Ambient radon diffuses into a chamber where subsequent disintegration of ions are electrostatically focused onto a thermoluminescent dosimeter (TLD) chip held at negative potential in a 900-volt electrostatic field. Each alpha particle striking the chip creates metastable defects in the crystal, which can be read and related to integrated radon concentration. An intervening layer of indictor-quality silica gel and a filter ensure that the air within the sample chamber is desiccated and particle free. A second TLD chip is exposed away from the electrostatic field (in the base of the housing) to check background levels of gamma radiation.

Lower Detectable Limit: 0.03 pci/l/week (LiF TLD)

Range:

Interferences:

Multiparameter Capability: Radon only

Performance:

Sampling Rate: diffusion, continuous

Accuracy:

Reproducibility:

Linearity:

Noise:

Lagtime:

Response Time: 5 hours with Whatman #41 filter

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift

Detector Response (LiF)--alpha 7.8 ±0.3 counts per pCi-hr/l
--gamma 0.036 counts per R/h per hour

Operation:

Temperature Range: <10° to >30° C

Temperature Compensation:

Relative Humidity Range: 0% to 80% for extended periods

Calibration:

Procedure:

Warm-Up Time: none

Unattended Period: >1 week (see remark #2)

Maintenance: replace desiccant as needed, check battery supply voltage

Power: 3 Everready Mini-max No. 493 batteries

Features:

Output: nanocoulombs from TLD reader

Training: none required for sampling

Options and Accessories:
RDX-727, battery, set of 3
RDX-351, spare desiccant chamber
RDX-458, replacement silica gel
20 cm Whatman #41 filter

Costs:

RDT-310: $575 (complete with batteries, desiccant, special shipping carton, and manual; TLD chips available upon request)
RDX-727: $30 each
RDX-351: $225
RDX-458 silica gel (per kg): $10
Filters: $10

Manufacturer:

EDA Instruments, Inc.
5151 Ward Road
Wheat Ridge, Colorado 80033

(303) 422-9122
TELEX: 450681

Head Office:
1 Thorncliffe Park Drive
Toronto, Canada M4H1G9

(416) 425-7800
TELEX: 06 23222 EDA TOR
Cables: INSTRUMENTS TORONTO

References:

Specifications

1. Manufacturer's bulletin
2. George, A.C. 1977. "A Passive Environmental Radon Monitor." In Radon Workshop. A.J. Breslin, ed. U.S. Energy Research and Development Administration, Report HASL-325, Health and Safety Laboratory, New York, New York, pp. 25-30.

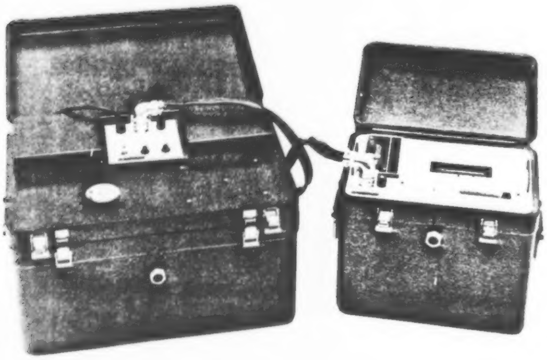
Operations experience

1. None available

Remarks:

This instrument is based on the Passive Environmental Radon Monitor (PERM) developed at the DOE Environmental Measurements Laboratory (George 1977).

Ordinary unattended exposure periods for this instrument exceed 1 week. The upper limit of exposure is operationally limited by desiccant life, which is determined by humidity. The dessicant can be baked in a home or laboratory oven and reused.



Weight: 32 kg

Dimensions: detector, 50 x 35 x 40 cm
computer, 12 x 10 x 10 cm

Principle of Operation:	Filtration/alpha and beta spectroscopy. Sample air is drawn through a filter for 2 minutes. Simultaneously, alpha and beta backgrounds are measured. The sample deposit on the filter is transported to the detector where alpha counts (entrance side of filter) and beta counts (exit side of filter) are simultaneously registered for 2 minutes. Radium A and radium C' are spectroscopically separated by energy. Concentrations of radium A, radium B, and radium C' plus working levels are computed automatically.
Lower Detectable Limit:	<0.001 WL
Range:	<0.001 to 100 WL
Interferences:	At extremely high working levels (>100 WL), the resulting gama background interferes with the performance of the beta detector.

Multiparameter Capability: Radium A, radium B, radium C' and working levels

Performance:

Sampling Rate: 30 to 60 l/min, continuous over 2-minute intervals

Accuracy:

Reproducibility: 7% at 10^{-3} WL, 2% at 10^{2} WL

Linearity: good

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: -10° to 40°C

Temperature Compensation: none needed

Relative Humidity Range: no effect

Calibration: standard source for detectors; flow meter for sample flow

Warm-Up Time: none

Unattended Period: 1000 samples (see remark #1)

Maintenance: exhaust filter should be changed periodically; sample filters can be reused as long as clean

Power: 110 V a.c.

Features:

Output: 8-digit LCD; thermal printer

Training: none required for sampling

Options:

Costs: $17,000

Manufacturer:

The Harshaw Chemical Company
Crystal and Electronics Department
6801 Cochran Road
Solon, Ohio 44139

(216) 248-7400

References:

Specifications

1. Manufacturer's bulletin, November 1980
2. M. Cox, Harshaw Chemical Company, personal communication, 1982

Operations experience

1. None available

Remarks:

With programmed time delays between samples, unattended operation is limited by data storage of 1,000 data points.

Users include EPA, DOE contractors, and a number of state departments of health

550007
TERRADEX
TERRADEX CORPORATION

Weight: Negligible

Dimensions: Type B (total alpha): 6 cm square card
Types F, M, and C: 9.5 cm high; 7.3 cm widest diameter
Types SF and SM: 2.2 cm high; 3.7 cm widest diameter

Principle of Operation: Passive integration of radon exposure. Alpha particles from radon in air or from radon progeny that have plated out on adjacent surfaces penetrate the detector and cause damage tracks. The damage tracks are chemically etched at the end of the exposure interval and counted. Average exposure is proportional to the counted tracks per unit area.

Lower Detectable Limit: 0.16 (pCi/l)-months (standard). Lower detectable limits are possible at an increased cost.

Range: 0.16 to 10^4 (pCi/l)-months; corresponds to 0.003 to 200 WL-months at a WL ratio of 0.5

Interferences: None

Multiparameter Capability: Type B measures total alpha activity (radon plus progeny)

Performance:

Sampling Rate: diffusion, continuous

Accuracy: 1.8% to 2.8% (relative standard deviation of calibration factor (Alter and Fleisher 1981)

Reproducibility: no batch-to-batch differences outside of normal counting statistics

Operation:

Temperature Range: -50° to 70° C

Temperature Compensation: none required

Relative Humidity Range: 0% to 100%

Calibration: none required in use

Procedure: static device, requires only placement and retrieval of detector

Unattended Period: depending upon application, <1 month to >1 year

Maintenance: none

Power: none required for sampling

Features:

Output: data report from manufacturer

Training: None is required for sampling; simple deployment instructions are supplied by manufacturer.

Options: Orders may specify "read as needed" to increase sensitivity; see cost section.

Costs:

Prices are controlled by number of detectors and desired sensitivity. For a minimum order of 50 detectors, the following schedule applies. Price includes readout and report of results.

Sensitivity Level* (p Ci/l)-months	Price per Detector
4.0	$16.50
1.0	33.00
0.2	66.00

(*Radon exposure for which the statistical uncertainty is 50%.)

If fewer than 50 detectors are ordered in 1 year, the service price is $50 per detector. At increased cost, the manufacturer can reread the detectors to an increased sensitivty level.

Manufacturer:

Terradex Corporation
460 North Wiget Lane
Walnut Creek, California 94598

(415) 938-2545
TELEX: 337-793

References:

Specifications

1. Manufacturers bulletin
2. Alter, H.W., and R.L. Fleisher. 1981. "Passive Integrating Radon Monitor for Environmental Monitoring." Health Phys. 40:693.

Operations experience

1. Alter, H.W. 1981. "Track Etch ™ Radon Detector Calibrations and Field Results." Presented at the U.S. Environmental Protection Agency International Meeting on Radon and Radon Progeny Measurement. Montgomery, Alabama.

2. Alter, H.W. 1981. "Indoor Radon Levels. Field Experience using the Track Etch™ Method." Presented at the International Symposium on Indoor Air Pollution, Health, and Energy Conservation. Amherst, Massachusetts.

3. Gingrioh, J.E., et al. 1982. "Monitoring Radon Around Uranium Mine and Mill Sites with Passive Integrating Detectors." Presented at the International Symposium on Management of Wastes from Uranium Mining and Milling, Albuquerque, New Mexico.

4. Alter, H.W., and R.A. Oswald. 1983. "Results of Indoor Radon Measurements Using the Track Etch Method." Accepted for publication, Health Phys.

Remarks: After the detector has been processed, it is itself a permanent record of the exposure and can be reread at any time. The manufacturer stores the exposed detector for future reference.

Shelf life of Track Etch detectors is 1 year if stored in packging provided by manufacturer.

9-1
INTERSCAN
SO_2 1240 and 4240
1 of 3

SULFUR DIOXIDE
PERSONAL/ACTIVE/ANALYZER

Weight: 3.6 kg, Model 1240
2.0 kg, Model 4240

Dimensions: 18.4 cm x 1.5.2 cm x
29.2 mm, Model 1240
17.8 cm x 10.2 cm x
22.5 cm, Model 4240

Principle of Operation:	Electrochemical oxidation. Gas molecules from the moving sample air stream pass through a diffusion medium and are adsorbed onto an electrocatalytic sensing electrode where subsequent reactions generate an electric current. The diffusion limited current is linearly proportional to SO_2 concentration.
Lower Detectable Limit:	1% of full scale
Range:	0 to 1 ppm, 0 to 5 ppm, 0 to 10 ppm (other ranges available)
Interferences:	Expressed as parts per million of interferent needed to give 1 ppm deflection:

Cl_2:	>500	H_2:	>500	NH_3:	45
CO:	>500	SAT. HC:	$>10^4$	NO:	>500
UNSAT. HC:	>500	NO_2:	10	SO_3:	$>10^4$

C_2H_5SH, H_2S, and CH_3SH require a special filter.

Multiparameter Capability: SO_2 only

Performance:

Sampling Rate: continuous

Accuracy: ±2% of full scale

Reproducibility: ±0.5%

Linearity: ±1% of full scale

Noise:

Lagtime: <1 second

Rise Time: 20 seconds

Retention Time:

Fall Time: 20 seconds

Zero Drift: ±1% full scale in 24 hours

Span Drift: <±2% full scale in 24 hours

Operation:

Temperature Range: 10° to 120° F

Temperature Compensation:

Relative Humidity Range:

Calibration: Standard gas mixture

Warm-Up Time:

Unattended Period: 10 hours on battery power

Maintenance:

Power: 4 Alkaline MnO_2 batteries for amplifier, 2 Ni-Cd for pumps LCD; 1 HgO battery for bias amplifier reference

Features:

Output: 0 to 100 mV full scale

Training: none required for sampling

Options: 1240, audible and visual alarm; 4240, audible alarm

Costs:

Model 1240: $1,675
Model 4240: $1,895

Manufacturer:

Interscan Corporation
P.O. Box 2496
21700 Nordhoff Street
Chatsworth, California 91311

(213) 882-2331
TELEX: 67-4897

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

SULFUR DIOXIDE
PERSONAL/PASSIVE/ANALYZER

Weight: 680 g (including leather case)

Dimensions: 152 x 76 x 51 mm

Principle of Operation: Diffusion/electrochemistry. Sulfur dioxide diffuses into an electrochemical cell, producing a signal proportional to SO_2 concentrations. The signal is digitized, incorporated into 1-minute averages, and stored. Nondestructive recovery of each 1-minute average is accomplished through a separate data reader. Data storage capacity is 2,048 1-minute averages.

Lower Detectable Limit: 0.5% of full scale

Range: 10 x TLV (TLV = 2 ppm)

Interferences: Expressed as parts per million of interferent needed to give 1 ppm deflection:

Cl_2:	>500	H_2:	>500	NH_3:	45
CO:	>500	SAT. HC:	$>10^4$	NO:	>500
UNSAT. HC:	>500	NO_2:	10	SO_3:	$>10^4$

C_2H_5SH, H_2S, and CH_3SH require a special filter.

Multiparameter Capability: SO_2 only

Performance:

Sampling Rate: diffusion, continuous

Accuracy: ±2% of reading, ±1 least significant digit (LSD), ±0.5% of FS (digital)

Reproducibility: ±1% reading, ±1 LSD

Linearity: 0.5% reading, ±1 LSD

Noise:

Lagtime:

Rise Time: 20 seconds

Retention Time:

Fall Time: 20 seconds

Zero Drift: ±1% reading, ±1 LSD in 24 hours

Span Drift ±1% reading, ±1 LSD in 24 hours

Operation:

Temperature Range: 30° to 120° F

Temperature Compensation:

Relative Humidity Range: 1% to 100%

Calibration: standard gas mixture

Warm-Up Time: <5 minutes

Unattended Period: up to 34 hours

Maintenance: calibration, battery replacement, sensor replacement

Power: long life 9-volt battery (Alkaline manganese dioxide, NEDA type 1604A); battery life is 125 hours continuous operation

Features:

Output: printout from data reader (see remark #1)

Training: none required for sampling

Costs:

Model 5240: $1,145

Manufacturer:

Interscan Corporation
P.O. Box 2496
21700 Nordhoff Street
Chatsworth, California 91311

(213) 882-2331
TELEX: 67-4897

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

Data readout is accomplished by a device available from:

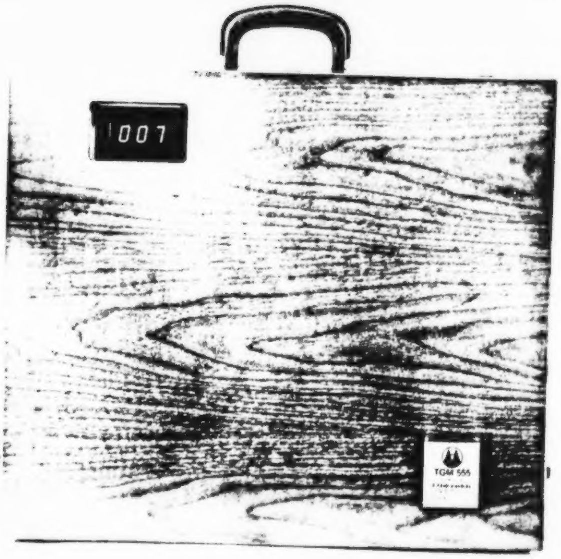
Metrosonics, Inc.
P.O. Box 23075
Rochester, New York 14692

(716) 334-7300

Interscan has also recently introduced the Model 2240 SO_2 personal monitor, which offers an LCD display of concentration instead of the data logging.

SULFUR DIOXIDE
PORTABLE/ACTIVE/ANALYZER

9-3
TGM 555
SULFUR DIOXIDE ANALYZER
1 of 3



Weight: 14 kg

Dimensions: 51 x 41 x 18 cm

Principle of Operation:	Automated wet chemistry/colorimetry. Sample air is continuously drawn through distilled water. Absorbed sample is reacted with pararosaniline and formaldehyde to form intensely colored pararosaniline methyl sulfuric acid, whose intensity is measured at 550 nm. Reagent handling and processing is automatic.
Lower Detectable Limit:	0.003 ppm (on 0 to 0.25 ppm full scale)
Range:	0 to 0.25 ppm (adjustable to 10 ppm)
Interferences:	

Multiparameter Capability:

Performance:

Sampling Rate: 250 ml/min, continuous

Accuracy:

Reproducibility: 1%

Linearity: <2% (up to 1 ppm)

Noise:

Lagtime: 6 minutes

Rise Time: 4 minutes to 95%

Retention Time:

Fall Time: 4 minutes to 95%

Zero Drift: <2% for 24 hours

Span Drift: <2% for 24 hours

Operation:

Temperature Range: 5° to 48° C

Temperature Compensation:

Relative Humidity Range: 5% to 95%

Calibration: liquid standards, permeation tubes, or standard gas dilution

Warm-Up Time: 20 minutes

Unattended Period: 18 hours on fully charged batteries

Maintenance: pump tubes changed once a month

Power: 12 V d.c. unregulated, 4 watts 115/230 V a.c., 50/60 Hz

Features:

Output: digital panel meter

Training: none required for sampling

Options: stream splitter (to extend range by a factor of 10 or 100)

Costs:

TGM 555: $5,395

Stream Splitter: $295

Manufacturer:

CEA Instruments, Inc.
15 Charles Street
Westwood, New Jersey 07675

(201) 664-2300
TELEX: 642128

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

DATA LOGGING
PERSONAL/ACTIVE/COLLECTOR

Weight: 250 grams

Dimensions: 25.4 x 7.6 x 2.2 cm

Principle of Operation:	Signal voltage is sampled and placed in temporary storage four times each second. At the end of every program-selected interval (10 seconds, 1 minute, 5 minutes, or 15 minutes), the average is calculated and stored time sequentially along with maximum peak value. At the end of the sampling period, the solid state memory is interrogated by a data reader that carries out selected calculations and prints out recorded data along with hourly and cumulative summaries, the 5-, 10-, and 15-minute intervals exhibiting highest values, and the peak value for the collection period.
Lower Detectable Limit:	
Range:	0 to 100 mV, 500 mV, 1 V, 5 V (others available upon request); two significant digits, one multiplier digit
Interferences:	

Multiparameter Capability: Single data channel plus time

Performance:

Sampling Rate: 4 scans per second, continous

Accuracy: ±0.5%

Reproducibility:

Linearity:

Noise:

Lagtime:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: -20° to 60° C

Temperature Compensation:

Relative Humidity Range: to 90%

Calibration:

Procedure:

Warm Up Time:

Unattended Period: Limited by total of 2,048 data values (See remark #1)

Maintenance:

Requirements: Power: 9-volt battery

Features: Output: (See remark #2)

Training: none required for sampling

Options: (See remark #3)

db-651V10	Table top METROREADER
db-652V10	Portable METROREADER
uk-651/V10	Modification kit (to update earlier readers for dl-331)
uk-652/V10	Modification kit (to update earlier readers for dl-331)
dc-431	METROMODEM to interface data logger to reader by phone lines
cc-305	Environmental case for METROLOGGER
ps-331	External power supply for extended operation
vr-331	Voltage reference source

Costs:

dl-331	$1,245
db-651V10	3,245
db-652V10	3,895
uk-651/V10	495
uk-652/V10	495
dc-431	925
cc-305	150
ps-331	50
vr-331	225

Manufacturer:

METROSONICS, Inc.
P.O. Box 23075
Rochester, New York 14692

(716) 334-7300

References: Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

The data logger has a capacity of 2,048 incremented data values. Thus, total sample period is ultimately limited by selected program interval as follows:

Interval	Total Sampling Time
10 seconds	5.6 hours
1 minute	34 hours
5 minutes	170 hours
15 minutes	21 days

Battery life is in excess of 120 hours; operation can be extended by addition of external battery or external power supply.

The METROREADER (db-651/V10 or db 652/V10) offers a direct printout onto 2-1/2 inch wide thermal paper. Optional interfaces allow direct transfers to xy plotters or to computer systems. The data logger itself does not allow for intermittent readings during sampling.

The options listed here have been selected from a much longer list.

The db-651/V10 and db-652/V10 readers are also used to output data collected by the Interscan 5140 CO monitor (summary #A3-5, this appendix).

METROSONICS has successfully interfaced the dl-331 data logging system to a number of industrial monitoring situations.

DATA LOGGING
PERSONAL/ACTIVE/ANAYZER

10-2
MAGUS GROUP DL-1
1 of 3

PHOTOGRAPH UNAVAILABLE

Weight: 482 g

Dimensions: 7.6 x 15.2 x 5.1 cm

Principles of Operation: Signal voltage is read every second and incorporated into a running average. At the end of the averaging period (1-hour in automatic mode) the average value along with day and time information is stored, the average is reset to zero, and a new average begins. Each logged average is retrievable.

Lower Detectable Limit: 1 mV

Range: -199 mV to 199 mV

Interferences: None

Multiparameter Capability: signal voltage, day, and time at each logging cycle

Performance:

Sampling Rate: 1 scan per second, continous

Accuracy: 0.5%

Repeatibility: 0.5%

Linearity: 0.5%

Noise:

Lag Time: <1 second

Rise Time: <1 second

Retention Time:

Fall Time: <1 second

Zero Drift: <0.5 mV

Span Drift: 0.5%

Operation:

Temperature Range: 0 to 40° C

Temperature Compensation: none

Relative Humidity Range: 0% to 99%

Calibration: factory procedure

Warm Up Time: None

Unattended Period: 113 hours (limited by storage capacity--see remark #1)

Maintenance: >1 year, except for periodic recharging of Ni-Cd batteries

Power: Six AA Ni-Cd batteries; reference battery is 2 mercury hearing aid batteries

Features:

Output: 4-digit LCD; 113 logged points

Training: none required for sampling

Options: See remark #2

Costs:

DL-1: $865 each; quantity discounts are available

Manufacturer:

MAGUS GROUP
2251 Grand Road, Suite A
Los Altos, California 94022

(415) 964-3230

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. None available

Remarks:

Current data storage capacity is 113 data points. Automatic mode increments storage function each hour, thus limiting unattended manual operation to 113 hours.

The manufacturer is currently developing a number of options and improvements to the DL-1. Direct dumping of logged data to a general purpose computer should be available by late 1982.

Available time did not permit review of this summary by a manufacturer's representative.

PHOTOGRAPH UNAVAILABLE

Weight: 240 g

Dimensions: 11 x 7 x 4.8 cm

Principle of Operation:	Signal voltage is quantitatively converted to frequency and a counter stores a running time-voltage integral. An independent LCD watch is mounted to display time.
Lower Detectable Limit:	
Range:	0-250 mV standard (other ranges available)
Interferences:	none
Multiparameter Capability:	Integrated time-voltage, time

Performance:

Sampling Rate: continuous

Accuracy:

Repeatability:

Linearity: 1% over 0 to 40° C

Noise:

Lag Time:

Rise Time:

Retention Time:

Fall Time:

Zero Drift:

Span Drift:

Operation:

Temperature Range: 0 to 40° C

Temperature Compensation: None required at 0 to 40° C

Relative Humidity Range:

Calibration: External reference signal

Warm-Up Time: None

Unattended Period: 40 hours nominal

Maintenance:

Power: 9-volt battery

Features:

Output: 4-digit LED display for integrated time-voltage; LCD for time

Training: none required for sampling

Options: See remark #2

Costs:

Each: $350

Lots of 10: $300 each

Manufacturer:

Custom Instrumentation
1027 Euclid Street
Santa Monica, California 90403

(213) 393-4760

References:

Specifications

1. Manufacturer's bulletin

Operations experience

1. Nagda, N.L., and M.D. Koontz. 1983. Exposures to Carbon Monoxide. GEOMET Report No.# EHF-1200. GEOMET Technologies, Inc., Rockville, Maryland.

Remarks:

The CI Data Logger was originally designed for use with the GE Carbon Monoxide Detector (see summary A3-3, this appendix), but is compatible with any analog signal source that meets input signal requirements.

The manufacturer will meet specific requirements for modification or changes at additional cost.

Available time did not permit review of this summary by a manufacturer's representative.

EPA REFERENCE AND EQUIVALENT METHODS

Continuous analyzers for CO, NO_2, SO_2, and O_3 that appear on EPA's "List of Designated Reference and Equivalent Methods" are enumerated here. Table A-2 displays the performance specifications for SO_2, O_3, CO, and NO_2. Specific instruments that have been designated reference or equivalent for each pollutant are listed in Table A-3. Addresses and telephone numbers of manufacturers are contained in Table A-4.

GLOSSARY OF INSTRUMENT TERMS

Principle of Operation: The chemical or physical basis for the measurement technique.

Lower Detectable Limit: The smallest quantity or concentration that causes a response equal to at least twice the noise level.

Range: The lower and upper detectable limits. Often, synonymous with full scale.

Interferences: Any substance or effect other than the measurement parameter that causes a measurable response in the instrument output.

Multiparameter Capability: The ability to measure more than one pollutant or parameter.

Collection Period: The amount of time specified to acquire sufficient sample mass.

Accuracy: The percentage difference between measured values and true values that have been established by acceptable reference methods. Accuracy is generally referenced to full-scale reading of the output.

Reproducibility: The degree of variation obtained when the same measurement is made with similar instruments and different operators; often expressed as a percentage of full scale.

Linearity: The maximum deviation between instrument response and the reading predicted from linear interpolation between calibration points at upper and lower scale values; often expressed as a percentage of full scale.

Noise: Spontaneous deviation from a mean output not attributable to input changes; often expressed as a percentage of full scale.

Lagtime: The time interval that elapses between a stepwise increase of input and the first corresponding change in output.

Table A-2. PERFORMANCE SPECIFICATIONS FOR AUTOMATED METHODS

Performance parameter	Units[1]	Sulfur dioxide	Photochemical oxidants (ozone)	Carbon monoxide	Nitrogen dioxide
1. Range	ppm	0-0.5	0-0.5	0-50	0-0.5
2. Noise	ppm	-0.005	0.005	0.50	0.005
3. Lower detectable limit	ppm	0.01	0.01	1.0	0.01
4. Interference equivalent					
Each interferent	ppm	±0.02	±0.02	±1.0	±0.02
Total interferent	ppm	±0.06	±0.06	±1.5	±0.04
5. Zero drift, 12 and 24 hours	ppm	±0.02	±0.02	±1.0	±0.02
6. Span drift, 24 hours					
20% of upper range limit	%	±20.0	±20.0	±10.0	±20.0
80% of upper range limit	%	±5.0	±5.0	±2.5	±5.0
7. Lag time	minutes	20	20	10	20
8. Rise time	minutes	15	15	5	15
9. Fall time	minutes	15	15	5	15
10. Precision					
20% of upper range limit	ppm	0.01	0.01	0.5	0.02
80% of upper range limit	ppm	0.015	0.01	0.5	0.03

Source: L.J. Purdue, "EPA Reference and Equivalent Methods," J. Air Pollut. Control Assoc. (30)9:992-96, Sept. 1980.

TABLE A-3. SUMMARY OF COMMERCIALLY AVAILABLE INSTRUMENTS FOR U.S. ENVIRONMENTAL PROTECTION AGENCY DESIGNATED REFERENCE AND EQUIVALENT METHODS FOR CO, NO_2, SO_2 AND O_3. (Parenthetical values indicate approved ranges.)

Pollutant	Methods
Carbon monoxide	Reference methods Nondispersive infrared (NDIR) - Bendix 8501-5CA (50) - Beckman 866 (50) - Horiba AQM-10-11 & 12 (50) - Horiba 300E/300SE (20, 50, 100) - Monitor Labs 8310 (50) - MSA 202S (50) Gas filter correlation (GFC) - Dasibi 3003 (50) - Thermo Electron 48 (50)
Nitrogen dioxide	Reference methods Gas phase chemiluminescence - Beckman 952A (0.5) - Bendix 8101-B&C (0.5) - CSI 1600 (0.5) - Meloy NA530R (0.1, 0.25, 0.5, 1.0) - Monitor Labs 8440E (0.5) - Monitor Labs 8840 (0.5, 1.0) - Phillips PW 9762/02 (0.5) - Thermo Electron 14 B/E & D/E (0.5)
Ozone	Reference methods Gas phase chemiluminescence - Beckman 950A (0.5) - Bendix 6002 (0.5) - CSI 2000 (0.5) - McMillan 1100-1, 2 & 3 (0.5) - Meloy OA325-2R & OA350-2R (0.5) - Monitor Labs 8410E (0.5)

(continued)

TABLE A-3. (Concluded)

Pollutant	Methods
Ozone (continued)	Equivalent methods Ultraviolet absorption - Dasibi 1003-AH, -PC, -RS (0.5, 1.0) - Monitor Labs 8810 (0.5, 1.0) - PCI Ozone Corp LC-12 (0.5) - Thermo Electron 49 (0.5, 1.0) Gas-solid phase chemiluminescence - Phillips PW 9771 (0.5)
Sulfur dioxide	Equivalent methods Flame photometric detection (FPD) - Bendix 8303 (0.5, 1.0) - Meloy SA185-2A (0.5, 1.0) - Meloy SA285E (0.05, 0.1, 0.5, 1.0) - Monitor Labs 8450 (0.5, 1.0) Pulsed ultraviolet fluorescence - Beckman 953 (0.5, 1.0) - Lear Siepler AM2020 (0.5) - Meloy SA700 (0.25, 0.5, 1.0) - Monitor Labs 8850 (0.5, 1.0) - Thermo Electron 43 (0.5, 1.0) Second derivative spectroscopy - Lear Siegler SM1000 (0.5) Automated wet chemical - Phillips PW9755 & PW9700 (0.5)

TABLE A-4. MANUFACTURERS OF STATIONARY ANALYZERS THAT APPEAR IN TABLE A-3

Beckman Instruments
Process Instruments Division
2500 Harbor Boulevard
Fullerton, California 92634
(714) 871-4848

Bendix Corp.,
Environmental and Process
Instruments Division
Box 831
Lewisburg, West Virginia 24901
(304) 647-4358

Columbia Scientific Industries
Box 9908
Austin, Texas 78766
(800) 531-5003

Dasibi Environmental Corp.
616 East Colorado Street
Glendale, California 91205
(213) 247-7601

Horiba Instruments, Inc.
1021 Duryea Avenue
Irvine, California 92714
(714) 540-7874

Lear Siegler, Inc.
74 Inverness Drive E
Englewood, Colorado 80112
(303) 770-3300

MSA
600 Penn Center Boulevard
Pittsburgh, Pennsylvaniz 15235
(412) 273-5172

Monitor Labs, Inc.
10180 Scripps Range Boulevard
San Diego, California 92131
(619) 578-5060

PCI Ozone Corp.
One Fairfield Crescent
West Caldwell, New Jersey 07006
(201) 575-7052

Phillips Electronic Instruments
85 McKee Drive
Mahwah, New Jersey 07430
(201) 529-3800

Thermo Electron Corp.
Environmental Instruments Division
108 South Street
Hopkinton, Massachusetts 01748
(617) 435-5421

Rise Time: The time interval that elapses between a stepwise increase of input and an output change equivalent to 90 percent of the input increment.

Retention Time: The time interval that elapses between a stepwise decrease of input and the first corresponding change of input.

Fall Time: The time interval that elapses between a stepwise decrease of input and an output change corresponding to 90 percent of the input change.

Zero Drift: The change of output over a stated time interval of unadjusted operations when input level is zero.

Span Drift: The change of output over a stated time interval of unadjusted operation when the input level is other than zero.

Temperature Range: The range of ambient temperatures over which the instrument meets or exceeds performance specifications.

Temperature Conditions: Mechanisms for adjusting the performance or response of temperature-sensitive components within the specified ambient temperature range.

Relative Humidity Range: The range of ambient relative humidities over which the instrument meets or exceeds performance specifications.

Calibration: The manner in which instrument response is referenced to known standards.

Warm Up Time: The amount of time required to achieve stable operation from initial startup.

Unattended Period: The amount of time over which the instrument will meet or exceed performance specifications. For many instruments summarized here, the principal limitation is battery life.

Maintenance: Highlights of service intervals recommended by the manufacturer.

Power: Specifications of alternating current and/or batteries required to operate the instrument.

Output: Defines the available readouts for the instrument.

Training: Defines the level of expertise required to operate (but not necessarily calibrate or repair) the instrument. Two categories of training are used: (1) "none required," implying that it can be successfully operated by nontechnical personnel with minimum instructions; (2) "recommended," implying that both a technical background and training will be needed. Note that for use of passive collectors, deployment can be carried out by nontechnical personnel with suitable instruction, but laboratory analysis will always require technical training.

Options: Additional features and accessories available from the manufacturer.

Costs: Manufacturer-supplied costs in U.S. dollars as of late 1982.

Manufacturer: Mailing address, telephone number, and (where available) Telex or other special contact information.

References: Published and other sources of information that were used to construct the summary. Separate listings are offered to denote specifications (generally manufacturer-supplied material) versus operations experience (user-suppled information).

Remarks: Additional comments that are beyond the scope of the format used.

APPENDIX B

ALTERNATIVES TO COMMERCIALLY AVAILABLE INSTRUMENTATION: STANDARD AND ACCEPTED METHODS

INTRODUCTION

Though a relatively wide range of commercially available instruments for indoor air quality monitoring has been identified in Appendix A, the possibilities of assembling measurement systems from simple components should not be ignored. This approach is frequently the only alternative, expecially for personal exposure monitoring, because suitable commercial instruments are not yet available for some pollutants.

The Gage Research Institute Personal Sampler (Mintz et al. 1982), which allows integrated personal sampling for SO_2, NO_2, and particulate matter for up to 10 hours, is an example of such approach. The device is built from commercially available components, makes use of previously tested procedures, and offers the advantages of size, portability, and multipollutant sampling that that could not be met from any single commercial source.

In this appendix, a number of methods are presented for measuring the following:

- Air exchange rates
- Inhalable particulate matter (including chemical characterization)
- Organic pollutants
- Formaldehyde
- Radon
- Fibrous aerosols.

The methods discussed here either represent standard practices endorsed by an appropriate organization or accepted technique published in refereed journals or are used by a number of researchers. Decisions to apply any of these approaches through in-house fabrication should be made only after careful review of the references listed at the end of each section.

Reference

Mintz, S., H.R. Hosein, B. Batten, and F. Silverman. 1982. "A Personal Sampler for Three Respiratory Irritants." J. Air Pollut. Control Assoc. 32(10):1068-69.

AIR EXCHANGE

The continual transfer of air across the building envelope is an important determinant for indoor pollutant levels. Depending upon the nature of indoor-outdoor pollutant contrasts, air exchange can serve to deliver cleaner outdoor air to reduce indoor levels; or, if outdoor levels exceed indoor levels, air exchange may contribute to indoor levels provided the decay of pollutants is not substantial. Additionally, because influx air matches outflux, both processes may be occurring simultaneously if two or more pollutants are involved.

Air exchange is produced from a complex interplay of many factors such as architecture, wind velocity, orientation of the structure, and indoor-outdoor temperature differences. These and other factors are summarized in Section 3 of this document.

Air exchange is commonly expressed in terms of the volume of air exiting (or entering) the structure per unit time (i.e., CFM or m^3/sec). To allow direct comparisons among structures of differing volumes, the air exchange rate is often standardized against the structural volume and expressed as air changes per hour (ACH). Thus, an air exchange rate of 1 ACH^{-1} implies that the volume of air entering (and consequently leaving) the structure in 1 hour is equivalent to the internal structural volume.

Four approaches to monitoring air exchange rate will be discussed here. Two of these--fan pressurization and tracer gas dilution--have been designated as standard practice by the American Society for Testing and Materials (ASTM) for evaluating infiltration rates on a single test basis. The third method, developed at the Brookhaven National Laboratory, can estimate longer term averages of total air exchanges, i.e., over sampling periods of several days or weeks in duration. A fourth technique, the ASHRAE crack method, relies upon measurement of the lengths of cracks such as those around windows and doors for calculation of air exchange. The summaries described below are included to introduce the methodology. Detailed information can be obtained from references indicated at the end of this section. ASTM (1980) is a particularly useful introduction to the topic.

Fan Pressurization

In the fan pressurization method (ASTM E779-81), the leakage characteristics of a structure are evaluated under controlled pressurization and depressurization. A range of positive and negative indoor-outdoor pressure differences is produced by using a variable-speed reversible fan, which is temporarily installed in an entry doorway. The fan can move large volumes of air into or out of the structure. At a constant indoor-outdoor pressure difference, all air flowing through the fan is compensated by equal flow through available openings in the building envelope. When all controllable external openings such as windows and doors are closed, the resulting data can be used to evaluate the leakage character of the building envelope and thus form the basis for comparisons of relative tightness. It should be noted that this method does not measure infiltration rates directly. Rather, it measures the effective leakage area through which infiltration occurs.

ASTM-specified equipment includes the following major components:

- Air-Moving Equipment--capable of sustained flows up to 5100 m^3/hr (3,000 CFM) at a constant rate
- Pressure-Measuring Device--capable of measuring pressure differentials with an accuracy of ±2.5 Pa (±0.01 inches of water)
- Air Flow Measuring System--to measure flows to within ±6 percent over the operating range of the air mover
- Air Flow-Regulating System--to regulate and maintain flows induced by the air-moving equipment to within 20 percent or less.

These components may be integrated to form a blower door assembly (see Figure B-1) to facilitate mounting the unit in the doorway and to offer convenient placement of readouts. Other configurations are acceptable, provided the test can proceed within the allowable tolerance limits. In addition to the above components, onsite measurements of winds and indoor and outdoor temperature are required.

Complete blower door assemblies that meet the requirements of ASTM E779-81 can be obtained from the following sources:*

HARMAX Corporation
6224 Orange Street
Los Angeles, California 90048
(213) 936-2673

Retrotec Energy Innovations, Ltd.
176 Bronson Avenue
Ottawa, Ontario, Canada K1R6H4
(613) 234-3368

The desired range of induced pressure differences is from 12.5 Pa to 75 Pa (0.05 to 0.3 inches of water), in increments of 12.5 Pa. In some cases, leakage rate may exceed fan capacity; nonetheless, a minimum of five data points on each side of zero is desired. Each data point consists of the measured pressure difference (Pa) and the corresponding fan flow (m^3/hr).

---

* The mentioning of trade names and commercial products does not constitute an endorsement.

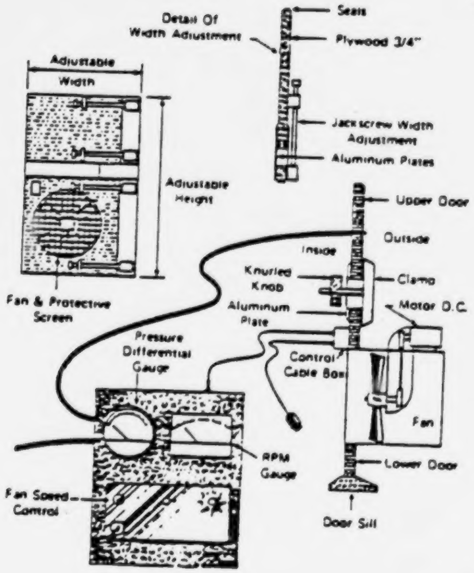

Detail Of Width Adjustment
Seals
Plywood 3/4"
Adjustable Width
Jackscrew Width Adjustment
Aluminum Plates
Adjustable Height
Upper Door
Outside
Inside
Knurled Knob
Clamp
Fan & Protective Screen
Aluminum Plate
Motor D.C.
Pressure Differential Gauge
Control Cable Box
Fan
RPM Gauge
Lower Door
Fan Speed Control
Door Sill

Figure B-1. Blower door assembly.*

---

* Source: ASTM E779-81

Preferred environmental conditions include winds of 5 mph or less, and indoor-outdoor temperature contrasts of 11° C or less to stabilize the environmentally induced pressure differential. Winds in exccess of 10 mph are to be avoided, and data collection under winds between 4 and 10 mph should be approached with caution.

All measured flows are converted to standard conditions (101.3 kPa pressure, 21.2° C temperature, 1.202 kg/m^3 air density) and plotted against corresponding pressure differences as shown in Figure B-2. In this particular experiment, fan pressurization was applied with the home in normal operating condition and with major vents sealed.

ASTM places an estimate of 10 percent or less on the uncertainty at a given pressure difference for the measurements. An additional sidelight of this method is the opportunity to identify individual routes of leakage by using visual tracers during any tightening procedures.

The fan pressurization data can be used to determine the effective leakage area, which acts as a simple index value to facilitate comparisons among experiments. Using the approach developed by Sherman and Grimsrud (1980), the pressure differential and flow data are fitted to the equation

$$Q = L\ (\Delta P)^n, \tag{1}$$

where Q is the flow (m^3/sec), and P is the pressure difference (Pa). The constants L and n are determined empirically to gain a best fit of the data. This equation can then be used to calculate the flow at any convenient pressure difference. The effective leakage area, A_{eff} (m^2) can then be calculated from the expression

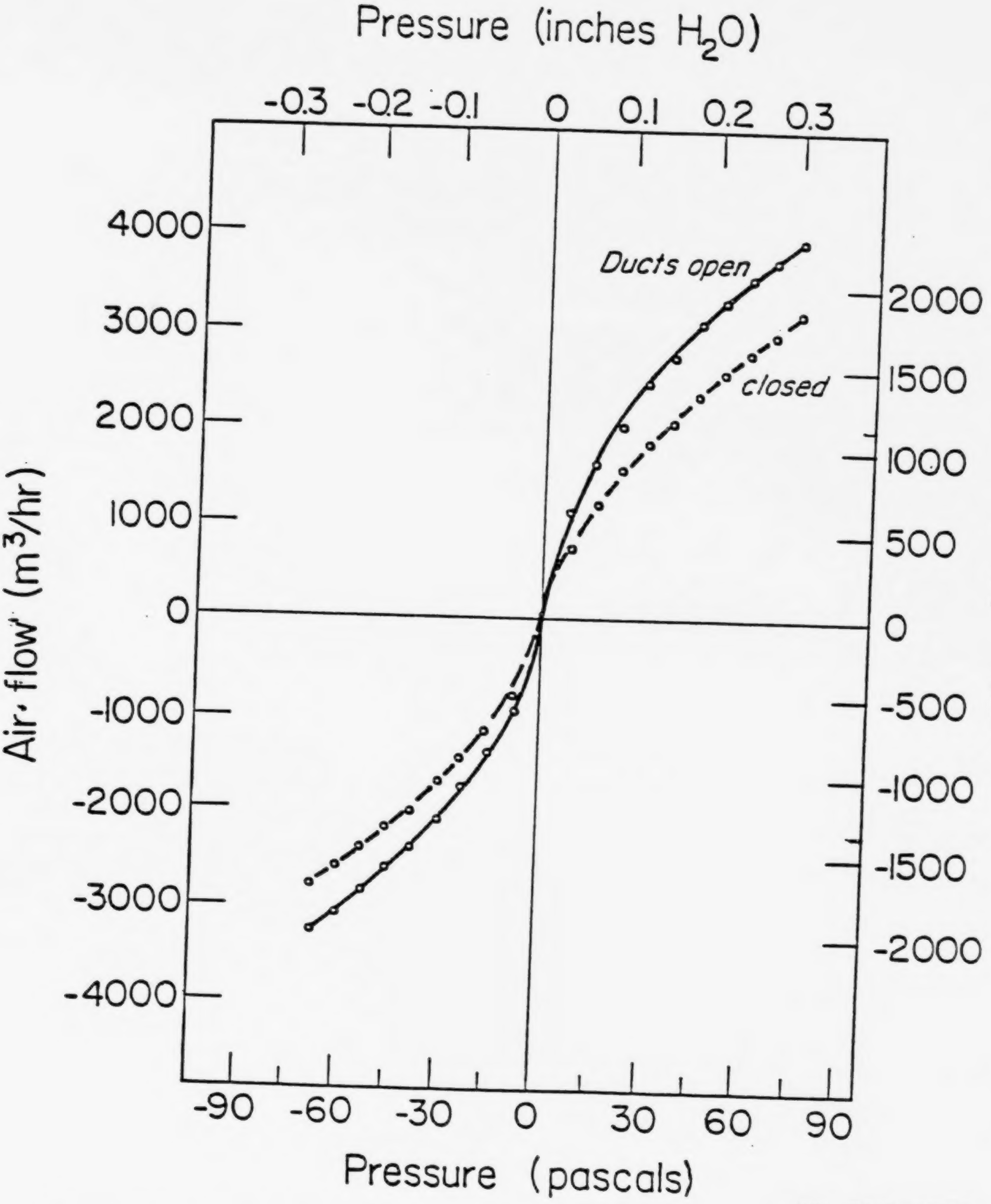
$$A_{eff} = Q\sqrt{\frac{\rho}{2\,\Delta\,P}} \tag{2}$$

where ρ is the density of air (1.2 kg/m^3). If the selected pressure difference is 4 Pa, this expression reduces to

$$A_{eff} = 0.387\ Q_4 \tag{3}$$

where Q_4 indicates that the flow corresponds to a pressure of 4 Pa.

The effective leakage area should not be confused with the air exchange rate. Rather, it is an estimate of the aggregate size of the openings through which infiltration may occur at rates determined by a variety of influences.



XBL 7810-6630

Figure B-2. Typical pressures differences measured by the fan pressurization method.

Source: Grimsrud et al. 1979.

Though not stipulated within the ASTM standard practice, the fan pressurization data can be used to calculate infiltration rates, provided local weather data are available. The basis for such calculations is discussed in Sherman and Grimsrud (1980) and in Blomsterberg and Harrje (1979).

Tracer Gas Dilution

In this method (ASTM E741-80), a small amount of tracer gas is injected into the indoor air space and thoroughly mixed. Within the structure, the concentration of tracer gas in air decreases over time because exfiltrating air is removing tracer gas while infiltrating air is essentially free of tracer gas. Thus, under ideal circumstances of perfect mixing and steady air exchange, the decay of tracer gas concentrations will follow the form:

$$C = C_0 e^{-\nu t} \tag{4}$$

where C is the tracer gas concentration at time t, C_0 is the initial tracer gas concentration, and ν is the air exchange rate (in air changes per hour, ACH, units). The air exchange rate can be calculated directly by rearranging equation (4) to form

$$\nu = \frac{1}{t} \ln \left(\frac{C_0}{C}\right) \tag{5}$$

when a succession of data points is obtained, the air exchange rate can be estimated graphically from a log-linear plot of concentration versus time or calculated through log-linear regression or finite difference methods to achieve a best fit.

In general, a desirable tracer gas has the following characteristics:

- It is easily and inexpensively measured at low concentrations and over short sampling times.
- It is not a normal constituent of air, or normally persists at concentrations many orders of magnitude below those to be used.
- The measurement technique is interference-free with regard to normal atmospheric constituents and thermodynamic conditions.
- It is inert, nonpolar, and not absorbed.
- It presents no safety or health hazard to occupants or operators.

As summarized in ASTM E741, no single tracer gas satisfies all of these conditions. However, as long as precautions are taken to ensure that initial concentrations are acceptably low, a number of gases become acceptable. Recommended practice is to restrain maximum concentrations to at least a factor of 4 below accepted limits. Under no circumstances should initial tracer gas concentrations exceed the OSHA time-weighted average for substances included in the latest OSHA-controlled list. This can be accomplished by relatively simple calculations to guide tracer gas releases. Sulfur hexafluoride (SF_6), nitrous oxide (N_2O), carbon dioxide (CO_2), and ethane (C_2H_6) are among the most commonly selected tracer gases. Use of these and other tracer gases is discussed in Grimsrud et al. (1980) and Harrje et al. (1982).

The general procedure involves releasing tracer gas at one or more points in sufficient quantities to produce useful initial concentrations. The method of release and quantities involved depend upon considerations of such things as the internal volume of the structure, the configuration of the air handling system, and estimates of allowable versus useful concentrations. In buildings that have central air handling systems, releases may be introduced directly to the intake. Otherwise, releases can be made from multiple points, and mixed with fans brought in. Generally, up to 30 minutes should be allowed for mixing prior to formal sampling.

Tracer gas samples should be taken every few minutes from two or more widely spaced locations on each story. This can be accomplished by a variety of methods as outlined in ASTM E741-80 and in Harrje et al. (1982).

Additional measurements of winds, temperature and humidity (indoors and outdoors), and local barometric pressure are required. Because air exchange rates attributable to infiltration can vary substantially due to changing environmental conditions, tracer gas dilution tests should be performed under a variety of environmental conditions (i.e., wind, temperature, humidity) and indoor-outdoor controls if average infiltration is desired.

Longer-Term Average Total Air Exchange (BNL/AIMS)

The previous methods represent viable approaches to evaluating the infiltration characteristics of a given structure. However, under realistic conditions extending over periods of many hours or days, infiltration can vary tremendously in response to a number of changing variables. Additionally, if the air space is occupied, total air exchange is often dominated by periods of natural ventilation and mechanical ventilation, and short-term measurements may prove to be inadequate.

One solution to this problem lies in a rather simple device developed at the Brookhaven National Laboratory (Dietz et al. 1981, 1982). The Brookhaven air infiltration measurement system (BNL/AIMS) makes use of a constant source of tracer gas accompanied by integrated sampling of the tracer. The main advantage that this approach offers over similar extended procedures (see

Condon et al. 1978, for instance) is that both the tracer source and sampler operate on diffusion principles. Thus, the advantage of compactness of source and sampler at the measurement site is combined with the use of sophisticated, expensive technology available in the laboratories.

The BNL/AIMS uses perfluorocarbon tracer (PFT) gases. These are chemically and biologically inert. Typical release rates are 12 to 14 nl/min at 24° C. The sampler is a 4 mm i.d. capillary adsorption tube (CAT) that samples PFTs at a rate equivalent to 0.14 ml/min. The CAT and PFT diffusion source are illustrated in Figure B-3. Sampling may proceed for periods as short as 1 day, or may be extended over a number of weeks if necessary. The upper limit has not been firmly established yet.

The average loss rate of air (i.e., the average outflux, assuming zero PFT in incoming air) can be approximated by:

$$R_v = \frac{R_s}{C_{ss}} \qquad (6)$$

where R_v is the average loss rate (m^3/min), R_s is the PFT source strength (nl/min), and C_{ss} is the average concentration (nl/m^3). Given a reliable estimate of the internal house volume, the average air exchange rate can be calculated from

$$\nu = \frac{R_v}{V_n} \qquad (7)$$

where ν is the average air exchange rate (ACH^{-1}) and V_n is the house volume (m^3).

Sampling procedures are straightforward and simple. One PFT source should be used for every 500 square feet of living space; attention should be paid to the floor plan to recognize a need for added sources. Sources should be near outside walls to take advantage of mixing patterns. Samplers should be located at least 1.5 m from any PFT source.* Recommended mixing time prior to sampling is 8 hours. This delay could present a problem in logistics because procedure would require a return visit or involvement of a resident to initiate sampling at the proper time. However, in situations where this delay period is very small compared to the total sampling period (i.e., sample period $\geq$1 week),

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* Special precautions must be taken to avoid undue contamination of samples from proximity to sources during storage, shipping, etc., as well.

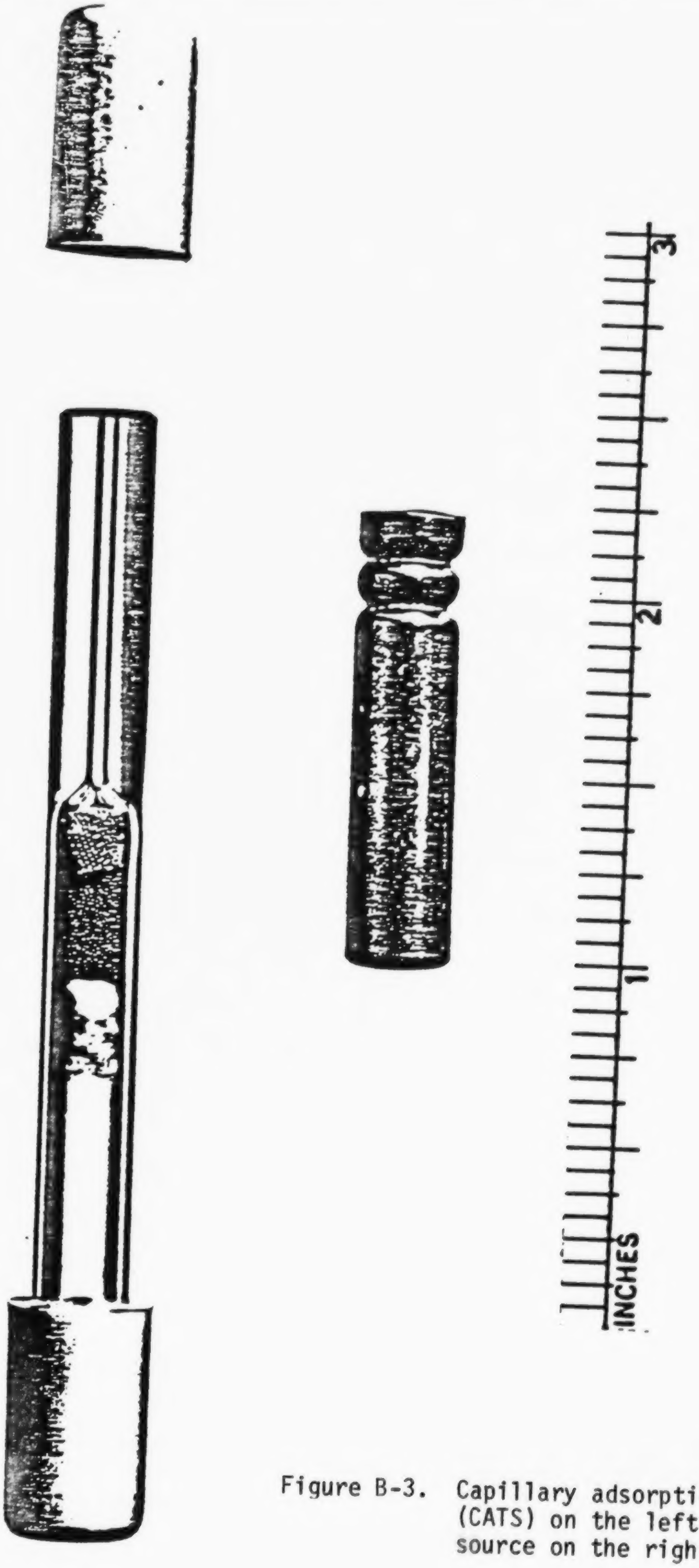

Figure B-3. Capillary adsorption tube sample (CATS) on the left PFT diffusion source on the right.

sources and samplers can be activated simultaneously without significantly affecting data. The samplers are activated by simply removing the cap; replacing the cap stops sampling.

The average concentrations are determined in the laboratory by gas chromatography. Source release rates are verified through periodic weighings.

ASHRAE Crack Method

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) offers a method for estimating infiltration rates from simple measurements that are compared to a series of leakage tables. The method is summarized in the ASHRAE Handbook of Fundamentals (ASHRAE 1977). Quantitative application is limited because, among other things, it is necessary to know the indoor/outdoor pressure difference. Additionally, even though ASHRAE provides tables of leakage characteristics for an extremely wide range of building components, they warn the user that leakage characteristics for these components as installed or built can be expected to differ from the as-tested condition. Hunt (1980) reported that overestimation of the pressure differences results in infiltration rates that range from "plausible" to "too high."

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INHALABLE PARTICULATE MATTER

A crucial need for indoor and personal monitoring is the ability to measure not only the mass of inhalable particulate matter but also the size distribution and chemical or elemental makeup. Sulfates, nitrates, and a number of metals such as lead need to be reliably determined using quiet, rugged personal monitors. However, no commercial instruments are available that meet all of these requirements.

Two recently developed sampling systems for size-selective collection of particulate matter have been used in personal monitoring and stationary monitoring approaches. The first, designed and tested by the Harvard University School of Public Health under EPRI sponsorship, uses a miniature cyclone to separate the respirable fraction for filter collection. The second, developed by NBS under EPA sponsorship, collects two size fractions--fine (<2.5 μm) and coarse (≥2.5 μm); separate sampling heads allow an upper size limit of 7, 10, or 15 μm. Though not commercially available at this time, both systems can be fabricated from readily available components and materials.

Harvard/EPRI Personal RSP Sampler

Design and development of the Harvard/EPRI sampler is summarized in Turner et al. (1979a and 1979b). Principal components of the sampler are displayed in Figure B-4, and specifications are listed in Table B-1. Sample air is drawn through a 10 mm cyclone whose size separation characteristics match criteria suggested by the American Conference of Governmental Industrial Hygienists. Respirable particles exiting the cyclone are collected on a 37 mm fluoropore filter (1 µm pore size) housed in a plastic cassette. Constant flow rate is achieved through a pump with variable voltage control. The Brailsford brushless pump, identified in the specifications, offered extended operating life (10,000 hours before servicing) and quiet operation. The system was configured to operate from self-contained batteries (14 to 20 hours) or from standard a.c. line current. A recharger for the battery pack is included as well.

Earlier versions of this sampling system were a straightforward adaptation of personal samplers devised for workplace monitoring, consisting of a Bendix BDX Super Sampler or a Mine Safety Appliance Portable Pump, Model 6. Problems with excessive noise and relatively short battery life, as these units were originally designed for 8-hour workshift applications, led to the current approach.

At the standard flow rate of 1.7 l/min, aerodynamic size characteristics of the aerosol passing through the cyclone are as follows:

Aerodynamic Diameter (µm)	2.0	2.5	3.5	5.0	10
Percent Passable	90	75	50	25	0

Because size separation is inertial, higher flow rates decrease the aerodynamic cutoff, lower flow rates allow larger particles to pass through. The Harvard/EPRI sampler exercises ±0.1 l/min control over a flow rate range of 0.5 to 3.0 l/min.

Cyclone efficiency is also affected by pulsations induced by pump action. A 3 cm diameter, 0.8 cm thick, rubber pulsation damper, installed between the filter cassette and the pump, allows sampling efficiency to approach that of a critical-orifice-controlled system.

Because the nylon cyclone is an insulator, it can accumulate a static charge that could significantly affect collection of charged aerosols. Blackman and Lippman (1974) reported higher collection efficiencies of charged aerosols below 4 µm compared with neutralized aerosols of the same aerodynamic diameters.

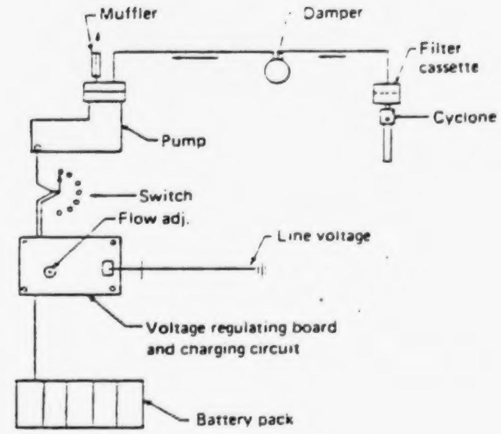

Muffler
Damper
Filter cassette
Cyclone
Pump
Switch
Flow adj.
Line voltage
Voltage regulating board and charging circuit
Battery pack

Figure B-4. Schematic of flow system.

Source: Turner et al. 1979a and 1979b.

TABLE B-1. SPECIFICATIONS OF HARVARD/EPRI SAMPLER

Size:	15.2 x 15.2 x 7.6 cm
Weight:	1.8 kg
Pump:	Brailsford Brushless TD-3LL or TD-3L
Battery pack:	Gould 12 V/1.2 SC cells Ni-Cd
Flow control:	Variable constant voltage
Range of operation:	0.5 to 3.0 lpm
Case metal:	Aluminum
Cyclonic separator:	10-mm nylon with filter
Features:	• Self-contained battery charger • No warmup time required to reach stable flow • 14- to 20-hour sample time on battery mode, indefinite from line voltage • Minimum maintenance brushless pump (10,000 hours before service) • Quiet operation

Source: Turner et al. 1979a and 1979b.

NBS-EPA Portable Ambient Particulate Sampler

A size-selective portable particulate monitor was developed by NBS under EPA sponsorship. Because the EPA was planning planning on changing its particulate standard to one involving two size fractions (fine and coarse) of inhalable particulates, a sampler capable of collecting both size fractions for later chemical analysis was required. The design and development of the NBS-EPA Portable Ambient Particulate Sampler is summarized in McKenzie et al. (1981) and in Bright and Fletcher (1983). Principal components of the sampler are shown in Figure B-5; specifications are listed in Table B-2. Sample air is drawn through a specially designed inlet where particles greater than the desired upper size limit (7, 10, or 15 μm) are removed. A Nucleopore filter (37 mm, 8 μm pore size), coated with Apiezon L grease to retard particle bounce, collects the coarse fraction (>2.5 μm), passing the fine fraction (<2.5 μm) for collection lection onto a PFTE filter (37 mm, 3 μm pore size). Constant sample flow of 6 l/min is supplied by a commercially available pump (Bendix BDX series) operating off batteries. The system fits into a 10 x 10 x 18 cm commercially available case.

The only noncommercial item in the system is the size selective inlet. However, the inlet can be easily fabricated on a standard lathe (Fletcher 1982). Figure B-6 indicates critical dimensions for the standard sleeve and inserts for the three cut points. The original system used aluminum for the inlet, though other materials are suitable.

Preliminary tests have shown no observed reductions in flow rate for fine filter loadings up to 100 μm; flow decreased by 7 and 12 percent at loadings of 220 and 400 μm, respectively (Fletcher and Bright 1982). These tests were performed in a room laden with cigarette smoke and required several consecutive days of sampling before flow reduction was observed.

Wind tunnel tests indicate that collection efficiency is independent of wind direction and wind speed at wind velocities below 0.9 m/sec. At higher wind velocities, collection efficiency decreases for larger particles. For example, less than 20 percent of 15 m particles were collected at 2.4 m/sec, regardless of orientation. For intermediate-sized particles, collection efficiency was 75 to 100 percent with a slight orientation effect (Fletcher and Bright 1982). The sampler should perform adequately in indoor settings, provided it is located in a draft-free area. In personal monitoring situations involving outdoor microenvironments and in fixed sampling outdoors, adjustments for altered collection efficiency due to winds may be warranted for the coarse fraction.

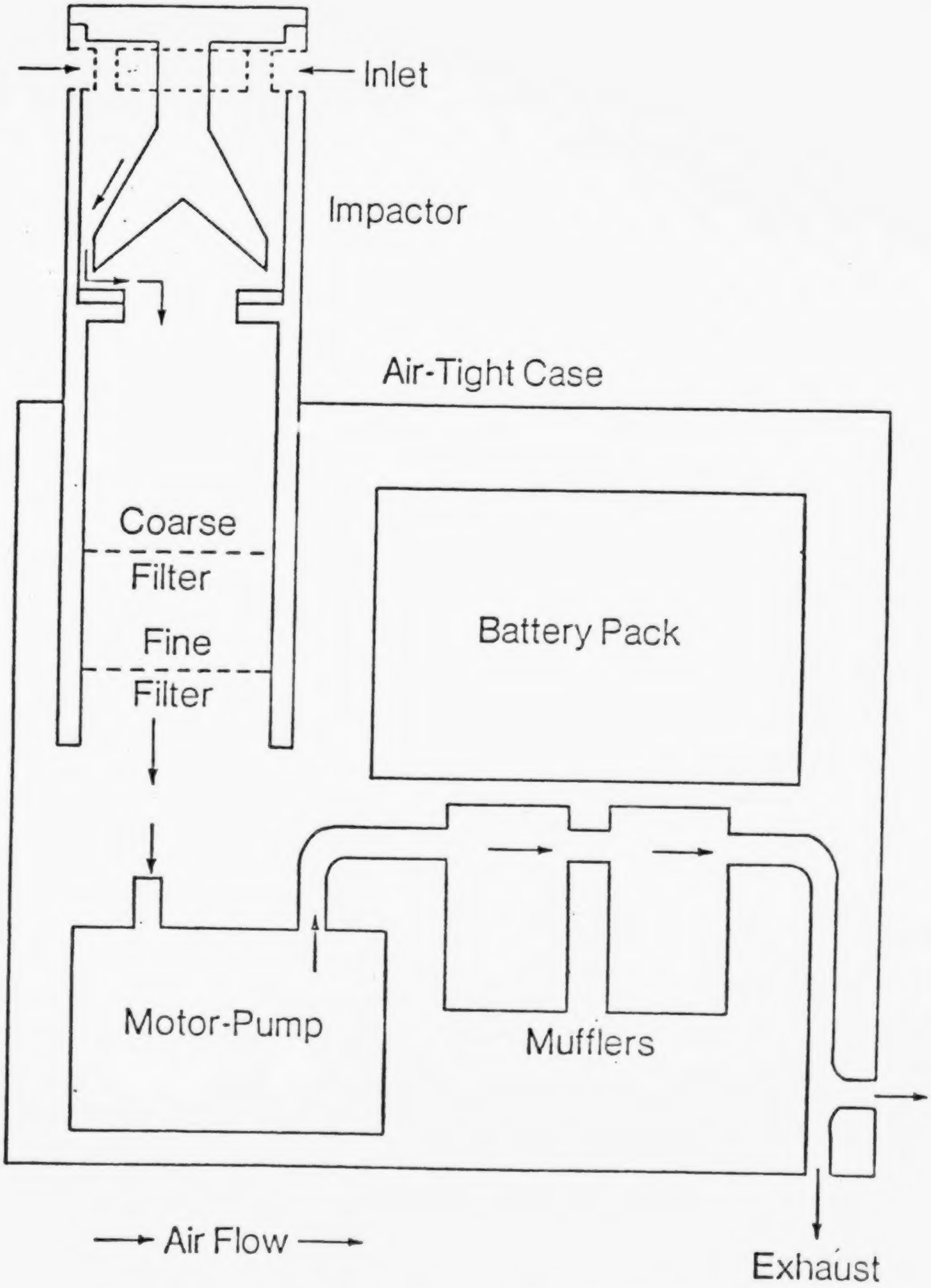

Inlet
Impactor
Air-Tight Case
Coarse
Filter
Fine
Filter
Battery Pack
Motor-Pump
Mufflers
Air Flow
Exhaust

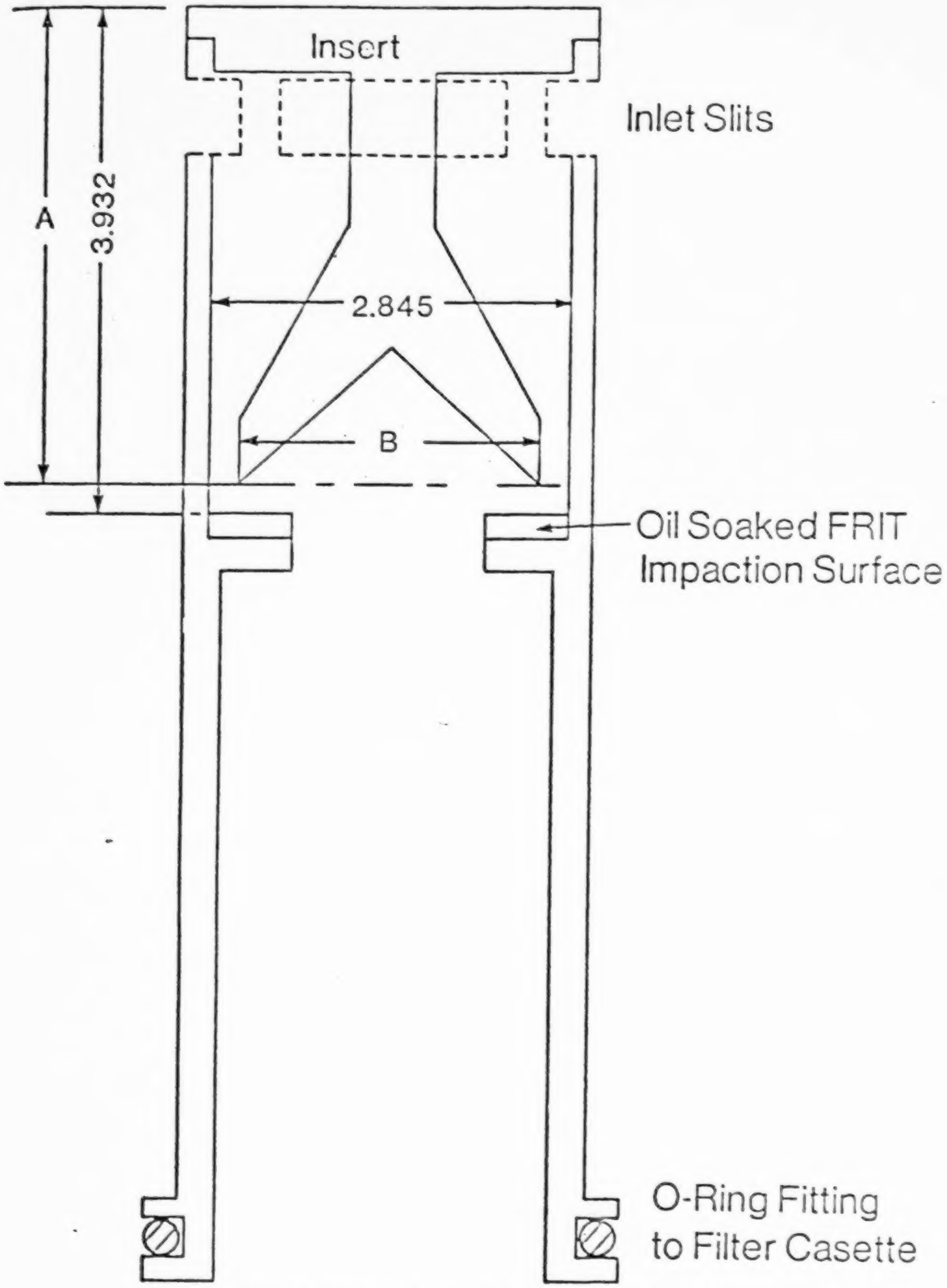
Figure B-5. Schematic diagram of the sampler.

Source: Fletcher and Bright 1982.

TABLE B-2. SPECIFICATIONS OF NBS PORTABLE AMBIENT PARTICULATE SAMPLER

Size:	10 x 10 x 18 cm
Weight:	1.6 kg
Pump:	Bendix (BDX 35, BDX 55, or BDX 60), or GILIAN
Battery pack:	Gould Ni-Cd
Flow Control:	±10 percent
Range of Operation:	5.5 to 6.5 l/min
Size Separation:	Fine fraction (<2.5 μm), coarse fraction (>2.5 μm); upper limit cut points available at 7, 10, 15 μm.
Battery Life:	Up to 60 hours
Features:	Two cut points with a variable upper limit allow matching with future EPA standard for inhalable particulates

Source: Fletcher and Bright 1982.



Insert
Inlet Slits
A
3.932
2.845
B
Oil Soaked FRIT
Impaction Surface
O-Ring Fitting
to Filter Casette

Critical Dimensions for Funnel Inserts

Cut Point (μm)	A (cm)	B (cm)
15	3.696	2.372
10	3.863	2.568
7	3.871	2.675

Figure B-6. Cross-section of the inlet to scale
(full length = 9.5 cm, 15 μm insert shown; critical dimensions in cm).

Source: Fletcher and Bright 1982.

Inorganic Analysis of Particulate Matter Samples

The inorganic constituents of particulate matter that are of interest to indoor air quality studies include sulfates and nitrates and a number of metals. Among the metals, principal interest has focused on lead, though all metallic and semimetallic elements may be of interest. As with organic aerosols (see page 232 of this appendix), inorganic material is usually collected in conjunction with standard gravimetric sampling for inhalable particulate matter. Constituents of interest may be extracted for quantitation, or the sample matrix may be submitted directly to nondestructive testing.

For any given constituent, a wide variety of standard methods and tested procedures are available. Extensive summaries are to be found in Katz (1980 and 1977). These range from relatively simple approaches involving extraction and spectrophotometric determination (as for sulfates and nitrates) to the more elaborate approaches of atomic absorption spectroscopy, neutron activation analysis, proton-induced X-ray emission (PIXE), and X-ray fluorescence (as for metals).

It should be noted that in many cases, methods for inorganic constituents were developed initially for source testing and for high-volume sampling. With the smaller sample masses that are generally captured with size selection and particularly with personal monitors for particulate matter, attention should be given to the manner in which analytical performance interacts with sample mass. That is, detection limits of the analytical method must correspond to acceptably low concentrations.

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ORGANIC POLLUTANTS

Relatively limited work has been carried out to characterize organic pollutants in the indoor environment. It is a highly complex topic and the list of airborne organic compounds of interest is large. Their presence has been attributed to combustion, to the use of solvents or solvent-containing products, and to emanations from manufactured materials (see, for instance, EPA 1981 and NAS 1981).

The majority of the monitoring approaches involve selectively concentrating target compounds on a collector, such as sorbent bed or filter, and transferring the sample to the laboratory for analysis. Continuing advances in analytical methods such as chromatography and mass spectrometry permit reliable detection and speciation from submicrogram quantities on a routine basis.

Comprehensive reviews of methods that may be adapted to indoor settings are to be found in Lamb et al. (1980) and in Katz (1980). Organic pollutants are classified into three broad classes as follows:

- Volatile Organic Compounds (VOC)--relatively low molecular weight species that exist in the vapor phase under ordinary ambient conditions. Examples include benzene and carbon tetrachloride.

- Semivolatile Organic Compounds (SVOC)--less volatile species such as PCBs and pesticides.

- Organic Aerosols--higher weight molecular species that usually exist in the liquid or solid phase under ordinary conditions. Examples include a wide range of polynuclear aromatic hydrocarbons condensed onto particulate matter.

Volatile Organic Compounds (VOC)

VOCs are ordinarily collected by drawing sample air through a sorbent bed that traps and retains target compounds. The VOCs of interest are later desorbed in the laboratory and quantitated. Sampling trains can be configured to meet the needs of monitoring strategies requiring personal monitoring, indoor fixed monitoring, or outdoor fixed monitoring.

A number of solid sorbents are available; Table B-3 summarizes selected sorbents and their properties. Use of Tenax-GC and activated charcoal, with glass or stainless steel tubes to house the sorbent material and constrain sample flow through the bed, has been particularly widespread. Captured material may be desorbed using solvent elution, and an aliquot may be injected into a gas chromatograph for quantitation. Solvent elution, however, partially offsets the advantages of sorbent trapping by rediluting the sorbent-concentrated sample.

In addition to its high collection efficiency, the particular advantage that Tenax offers is the thermal stability to allow desorption at high temperatures (up to 300° C). Charcoal has so far shown questionable utility in this regard (see Table B-3).

Breakthrough and inherent limits of detection of the analytical system (i.e., GC, GC/MS, etc.) are of central importance in considering the use of solid sorbants in sampling VOCs. Breakthrough refers to saturation capacity of the sorbent bed so that elution occurs during sampling, and subsequent quantitation could severely underestimate concentrations. Breakthrough volume (i.e., the volume of air sampled beyond which more than 50 percent of a particular target compound entering the front of the sampling cartridge is lost at the rear) is a useful concept in determining optimum sample volumes and the size of a sorbent bed needed to meet the detection limit of the analytical system. Table B-4 summarizes breakthrough volumes (liters) determined by Pellizzari et al. (1981) to guide sampling procedures for VOCs in the Total Exposure Assessment Methodology (TEAM) Study. In their approach a total sample volume of 0.025 m^3 (25 l) was selected to stay below the breakthrough volumes of most target compounds.

Once sample volume and sorbant quantities have been determined, glass or stainless steel collector tubes can be configured. The inlet and outlet are usually plugged with glass wool to provide support. Extreme care must be exercised in all handling of the sorbant to preclude contamination. Usual precautions include extended Soxhlet extraction of virgin and reused Tenax, followed by vacuum drying at 100° C. Mesh sorting and tube packing are performed under clean room conditions. Storage and handling when not actively sampling should be through the use of clean, sealed containers.

A number of vacuum sources exist to allow configurations for personal and fixed sampling over desired time periods (see Wallace and Ott 1982).

TABLE B-3. PROPERTIES OF SELECTED ADSORBENTS

Adsorbent	Temp. limit (°C)	Cond. temp. (°C)	Des. temp. (°C)	Chemical composition	Major thermal decomposition products	Background level	Δp* (psig)	Capacity	Desorption	Range of utility (δ_m)
Tenax-GC (35/60 mesh)	400	320	300	2,6-Diphenyl-p-phenylene oxide	Alkyl benzene Styrene Benzene Alkyl phenols	Good (none detected above system background)	160	Should efficiently trap intermediately (and less) volatile compounds with slightly less affinity for polar compounds.	Very amenable to thermal desorption for intermediately (and all higher) volatile compounds.	~950->2800
Porapak R (50/80 mesh)	250	235	150-220	n-Vinyl pyrrolidone	Vinyl pyrrolidone Pyrrolidone Pyrrilidiene	After conditioning at 235° C, background upon desorbing is Poor at 220° C (well above system background); Fair at 150° C (slightly above system background)	~1.1#	Should efficiently trap intermediately (and less) volatile compounds with slightly greater affinity for polar compounds.	Very amenable to thermal desorption for intermediately (and all higher) volatile compounds.	~750-~1500
Porapak N (50/80 mesh)	190	175	150	n-Vinyl pyrrolidone	Vinyl pyrrolidone Pyrrolidone Pyrrilidiene	Poor (well above system background)	1.1	Should efficiently trap intermediately (and less) volatile compounds with slightly greater affinity for polar compounds.	Very amenable to thermal desorption for intermediately (and all higher) volatile compounds.	~750-~1500
Ambersorb XE-340	400	320	300	Carbonized styrene-divinyl benzene	None observed (after conditioning at 350° C and observing on GC/MS)	Good (none detected above system background)	0.6	Should efficiently trap highly (and all less) volatile compounds with slightly greater affinity for polar compounds.	Questionable amenability to thermal desorption for all but highly volatile hydrocarbons.	~450-~750
SKC Activated Charcoal	400	320	300	Carbonized organics	None observed	Good (none detected above system background)	~0.6#	Should efficiently trap highly (and all less) volatile compounds with much greater affinity for polar compounds	Questionable amenability to thermal desorption for all but highly volatile hydrocarbons.	~350-~600

*Pressure drop across tapered tubes containing 1.0 g of adsorbent at a 3 l/min flow rate.
#Estimated.

Source: Brooks et al. 1979.

TABLE B-4. TENAX GC BREAKTHROUGH VOLUMES (LITERS) FOR TARGET COMPOUNDS*

Compound	boiling point (°C)	Temperature (°F)					
		50	60	70	80	90	100
Choloroform	61	56	41	32	24	17	13
Carbon tetrachloride	77	45	36	28	21	17	13
1,2-Dichloroethane	83	71	55	41	31	24	19
1,1,1-Trichloroethane	75	31	24	20	16	12	9
Tetrachloroethylene	121	481	356	261	192	141	104
Trichloroethylene	87	120	89	67	51	37	28
Chlorobenzene	132	1989	871	631	459	332	241

Source: Pellizzari et al. 1981.

*For a Tenax GC bed of 1.5 cm i.d. x 8.0 cm.

Semivolatile Organic Compounds (SVOC)

SVOCs--particularly polychlorinated biphenyls and pesticides--are generally sampled by drawing sample air through polyurethane foam (called PUF or PFOAM). Target compounds are subsequently extracted in the laboratory and analyzed.

Lewis and MacLeod (1982) have developed an approach that is adaptable to personal monitoring as well as fixed sampling. Cylindrical PUF plugs (22 mm diameter x 7.6 cm) are cut from sheet stock open cell polyether type polyurethane foam (0.022 g/cm^3) that is ordinarily used for upholstery. Cylindrical cuts are facilitated by a stainless steel cutting dye. Preparation requires extended Soxhlet extraction. Plugs are inserted into a borosilicate glass tube (20 mm i.d. x 8 cm), one end of which is drawn down to a 7 mm o.d. open connection to allow attachment of a vacuum line.

Sample cartridges should be protected from contamination by wrapping in hexane-washed aluminum foil. Nominal sample volumes may be as high as 3 m^3 (i.e., 4 l/min for 12 hours, for instance). PUF plugs are removed from the cartridges in the laboratory, target compounds are extracted with a Soxhlet extractor using diethylether in hexane, and quantitation may be carried out using GC or high performance liquid chromatography (HPLC). Compounds of interest can be measured at levels as low as 1 ng/m^3.

Table B-5 indicates the range of compounds that can be sampled with this system. Sampling can be extended to include VOCs as well as fortifying collection efficiency for some SVOCs by inserting a Tenax sandwich between two shortened PUF plugs in a single cartridge.

Organic Aerosols

In many cases, sampling for organic aerosols is done in conjunction with standard gravimetric sampling (i.e., as for inhalable particulate matter). Attention in this area has focused largely on polynuclear aromatics (PNA), which represent ubiquitous combustion products that have demonstrated animal carcinogenicity.

Once extracted from the filter by an appropriate solvent, PNAs may be quantified (as a class or as individual compounds) by a variety of methods including routine GC, HPLC, and thin layer chromatography (TLC) (see Katz 1980).

Spectroscopic techniques are also coming into use. In particular, room-temperature phosphorescence (RTP) spectroscopy has overcome the need for cryogenic treatment (Vo-Dinh et al. 1981). In this method, PNAs are isolated by liquid chromatography and diluted in ethanol. A 3 μl aliquot is spotted onto a filter previously treated with a solution of heavy metal salts, and irradiated with ultraviolet light. Resulting phosphorescence is enhanced by the heavy metals and can be compared to reference spectra levels to identify and quantify PNAs.

TABLE B-5. COLLECTION EFFICIENCIES

Compound	Quantity introduced, μg	Air volume m^3	Collection efficiency $\overline{x}$, %	RSD, %	n
Organochlorine pesticides					
α-Hexachloracyclohexane	0.005	0.9	115	8	6
γ-Hexachlorocyclohexane (lindane)	0.05-1.0	0.9	91.5	8	5
Technical chlordane	0.2	0.9	84.0	11	8
ρ,ρ'-DDT	0.6, 1.2	0.9	97.5	21	12
ρ,ρ'-DDE	0.2, 0.4	0.9	102	11	12
Mirex	0.6, 1.2	0.9	85.9	22	7
2,4-D Esters:					
Isopropyl	0.5	3.6	92.0	5	12
Butyl	0.5	3.6	82.0	10	11
Isobutyl	0.5	3.6	79.0	20	12
Isooctyl	0.5	3.6	>80*	20	12
Semivolatile organochlorine compounds and PCB					
1,2,3-Trichlorobenzene	1.0	0.9	6.6#	22	8
1,2,3,4-Tetrachlorobenzene	1.0	0.9	62.3#	33	5
Pentachlorobenzene	1.0	0.9	94.0	12	5
Hexachlorobenzene	0.5, 1.0	0.9	94.5	8	5
Hexachlorocyclopentadiene	1.0	0.9	8.3#	12	5
2,4,5-Trichlorophenol	1.0	0.9	108	3	5
Pentachlorophenol	1.0	0.9	107	16	5
Aroclor 1242	0.1	0.9	96.0	15	6
Aroclor 1254	0.1	0.9	95.0	7	6
Aroclor 1260	0.1	0.9	109	5	11
Organophosphorus pesticides					
Dichlorvos (DDVP)	0.2	0.9	72.0	13	2
Ronnel	0.2	0.9	106	8	12
Chlorpyrifos	0.2	0.9	108	9	12
Diazinon	1.0	0.9	84.0	18	18
Methyl parathion	0.6	0.9	80.0	19	18
Ethyl parathion	0.3	0.9	75.9	15	18
Malathion	0.3	0.9	100§		

---

* Not vaporized. Value based on % retention efficiency of 81.0 (RSD = 10%, n = 6).

# % Collection efficiencies were 98%, 98%, and 97% (n = 2), respectively, for these three compounds by the PUF/Tenax GC "sandwich" trap.

§ Decomposed in generator; value based on % retention efficiency of 101% (RSD = 7%, n = 4).

Source: Lewis and MacLeod 1982.

Legend:

$\overline{x}$ = average collection efficiency, in percent
RSD = relative standard deviation, in percent
n = number of trials

It should be noted that in many cases analytical methods for PNAs were initially developed for source testing and for high volume ambient sampling. With the smaller sample masses that are generally captured with size selection and particularly with personal monitors for particulate matter, attention should be given to the manner in which analytical performance interacts with sample mass. For example, detection of nanogram quantities may well force collection volumes beyond the flow capacity of the sampler. Or worse still, a short sampling period coupled to a large sample volume could severely alter air flow patterns in some indoor settings. In many cases, compensation can be forced by reducing the extraction volume, or by pooling replicate samples for composite analysis.

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FORMALDEHYDE

The most popular methods for measuring indoor formaldehyde concentrations employ aqueous bubblers for air sampling followed by colorimetric analysis. In applying these methods, two bubblers in series, operating under vacuum, are recommended. The collection efficiency of one bubbler is approximately 80 percent; the second bubbler boosts the total collection efficiency to approximately 95 percent. The contents of each bubbler may be analyzed separately or the contents may be pooled. Additionally, sampling frequently takes place with the bubblers chilled. Under these conditions, a vapor trap (simply an empty bubbler) should be installed between the second bubbler and the pump.

Chromotropic Acid Method

Detailed procedures for the Chromotropic Acid Method may be found in NIOSH P&CAM 125 (NIOSH 1977). Sample air is bubbled through a 1 percent sodium bisulfate solution. In the laboratory, chromotropic acid reagent is added to an aliquot of the absorbing solution. Concentrated sulfuric acid is added slowly to the absorbing solution, to avoid spattering due to the exothermic reaction. The treated aliquot is allowed to cool to room temperature. Absorbance is read at 580 nm in a spectrophotometer. Formaldehyde content is determined from a curve derived from fresh standard formaldehyde solutions.

Concentrations as low as 0.1 ppm can be determined in a 25 liter air sample (based on 20 ml of absorbing solution and a difference of 0.05 absorbance units above blank). Sensitivity can be boosted by increasing the sample air volume (i.e. extending the sample period or increasing the flow rate) or by decreasing the amount of absorbing solution in the bubblers. Godish (1981) recommends a sample flow rate of 1 liter per minute, a 90-minute sample period and 10 ml absorbing reagent in each impinger.

Modified Pararosaniline Method

Detailed procedures for the Modified Pararosaniline Method may be found in Miksch et al. (1981). Sample air is bubbled through deionized, distilled water that is kept chilled (i.e., ice bath or refrigerator) during sampling. In the laboratory, acidified pararosaniline is added to an aliquot of the sample solution, and thoroughly mixed. Then, sodium sulfite reagent added and thorougly mixed. The treated aliquot is placed in a 25° C water bath and color development is allowed 60 minutes. Absorbance is read at 570 nm in a spectrophotometer. Formaldehyde content is determined from a curve derived from fresh standard solutions.

Concentrations as low as 0.025 ppm can be determined in a 60-liter air sample (based on 20 ml of absorbing solution and a difference of 0.05 absorbance units above blank).

Additional Formaldehyde Methods

A visual colorimetric screening method based on the methylbenzothiazolin (MBTH) technique has been reported by Matthews and Howell (1981a). This method is specific for all aliphatic aldehydes, but in domestic indoor air settings, formaldehyde is expected to be the principal contributor. Sampling is carried out using a passive semipermeable membrane device with water as an absorbant. When the color change is fully developed, the solution is compared to a reference color chart to determine concentration range.

Formaldehyde concentrations may also be determined by collection onto various solid sorbants followed by laboratory analysis. Beasley et al. (1980) suggest collection onto silica gel coated with 2,4-dinitrophenylhydrazine (2,4-DNPH). During sampling, formaldehyde forms a specific hydrazone which is extracted using acetonitrile and quantified by HPLC with UV detection.

Matthews et al. (1981b) have developed a simple approach using 13x molecular sieve collection followed by water-rinse desorption and colorimetric analysis based on the Modified Pararosaniline Method. This approach has been tested for passive sampling as well as pumped sampling, and has shown high collection efficiencies (>99.9 percent) and stability (shelf life of sealed exposed media at <38° C is at least 1 week). Care must be exercised in applying this technique, however, because the sorbant also has an affinity for water; one study is limiting sampling to 2 liters per minute for 30 minutes (Battelle 1982). Nonetheless, a lower detection limit of 0.025 ppm is to be expected.

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RADON

Using commercially available passive devices, average indoor radon concentrations can be measured over periods of several months using the Track Etch™ Method (Alter and Fleischer 1981) or over periods of a few weeks using thermoluminescent dosimetry (George and Breslin 1977). For shorter periods (i.e., on the order of a few days), no commercially available passive devices were identified. George (1982), however, has recently reported a passive method based on activated carbon adsorption and gamma ray detection that is inexpensive, maintenance free, and can be easily fabricated from commercially available components. The activated carbon canister method exhibits a lower limit of detection for radon of 0.2 $nCiM^{-3}$ for an exposure period of 72 hours.

The device, originally based on the M11 Canister developed by the U.S. Army Chemical Corps in World War II, is a cylindrical container 5 cm high by 10 cm diameter, which is filled with 200 g of coconut shell carbon (i.e., to a depth of 4.5 cm). A metal screen and retainer a ring hold the activated carbon in place. The canister is fitted with a removable metal cover taped in place to provide an air-tight seal when not sampling.

To sample, the metal cover is simply removed in the area to be monitored and resealed at the end of the sampling period. The amount of sorbed radon in the carbon bed is determined by measuring the gamma rays produced by the decay of radon progeny. George used an 8 x 8 cm crystal coupled to a compact pulse height analyzer and printer. Total gamma activity from the radon progeny decay is determined from the total absorption peaks of ^{214}Pb(0.242, 0.294, and 0.352 MeV) and of ^{214}Bi(0.609 MeV). Average radon concentration may be calculated from the following equation:

$$\mathrm{Rn} = \frac{\text{net CPM}}{\mathrm{E \times Ts \times DF \times CF}}$$

where

Rn = Average radon concentration during exposure ($nCiM^{-3}$)

net CPM = Gamma counts per minute minus background

E = Calibration factor for gamma analyzer (CPM/nCi)

Ts = Exposure period in minutes, which generally should not exceed 5,500 minutes (3.82 days--the half life of radon)

DF = Decay factor for radon from midpoint of exposure until time of counting

CF = Calibration factor for canister ($nCi\ min^{-1}/nCiM^{-3}$).

Calibration tests showed no discernible differences in response for temperatures ranging from 18° C to 27° C. Response of the device does, however, decrease with exposure time and humidity. Figure B-7 illustrates this effect. The middle curve (RH = 40% to 70%) represents conditions most often encountered indoors. Corrections for humidity can be made by determining the amount of water sorbed during exposure gravimetrically and applying a second calibration curve (See Figure B-8).

These devices are reuseable. Before sampling, residual radon (and sorbed water) can be purged with heated air (100° C for 5 minutes) or by baking in an oven at 120° C for several hours. Exposed canisters can be counted up to 10 days after the end of exposure, thus allowing the devices to be transferred by mail. Exposure periods should not exceed 3 to 4 days.

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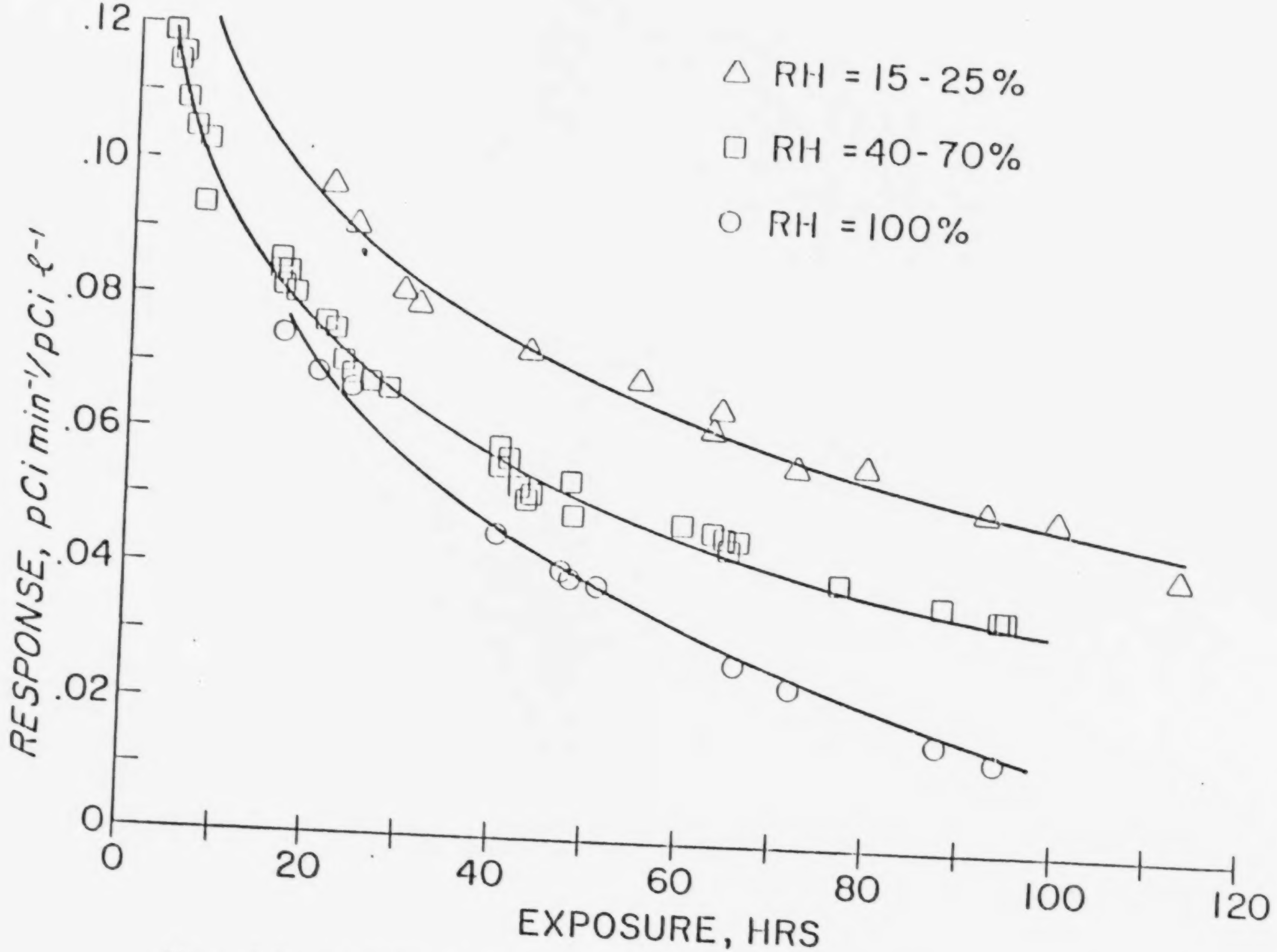

Figure B-7. Variation of radon adsorption versus time at different humidities.

Source: George 1982.

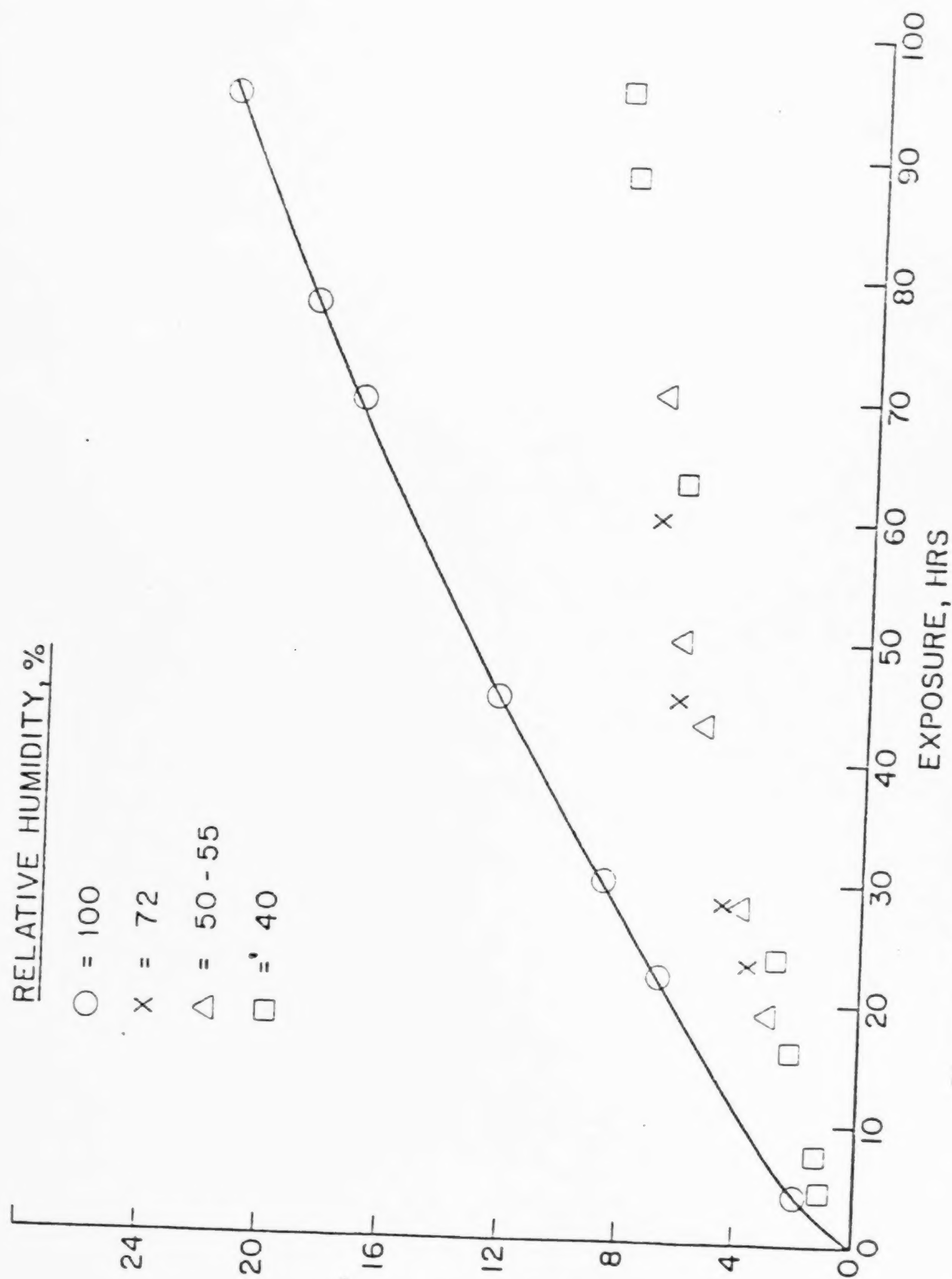

Figure B-8. Water adsorption versus time at different humidities.

Source: George 1982.

FIBROUS AEROSOLS

Airborne fibers of interest in indoor air quality monitoring include all varieties of asbestos; a number of manufactured fibers such as mineral wools, fibrous glass wool, and some ceramics; and organic fibers such as animal dander and wood dusts (EPA 1981). Manual sampling for fibrous aerosols generally consists of drawing sample air through a membrane filter and quantifying fiber concentrations through optical microscopy or, when resources permit, analyzing the sample by sophisticated analytical procedures such as electron microscopy and X-ray diffraction.

Optical Microscopy

Detailed procedures for determining exposure to airborne asbestos fibers though filter collection and optical sizing and counting are available in NIOSH P&CAM 239 (NIOSH 1977). In this method, asbestos fibers are defined as particles of physical dimension greater than 5 μm with a length to diameter ratio of 3 to 1 or greater. It should be noted that the method is not asbestos-specific. Rather, the method assesses all fibers that meet the dimensional requirements. Further, the resolution limits of optical microscopy along with the assigned cutoff of 5 μm precludes assessing fibers that fall below this size range. Thus, the method provides an index of asbestos exposure rather than a true measure of asbestos fiber counts.

Sampling is usually carried out using a 34 mm membrane filter with 0.8 μm pore size mounted in an open-faced cassette. Sample flow is selected upon consideration of desired sampling period and minimum detection limits. For personal monitoring applications, a number of battery-powered pumps with stable flow rate control are available.

At the end of sampling, exposed filters are resealed in their cassettes and taken to the laboratory. In the laboratory, the filters are sectioned, mounted onto microscope slides, and chemically treated to make the membrane filter transparent. The slides are then examined using phase contrast illumination at a magnification of 400 X to 500 X to acquire a statistically valid count of fibers that meet the sizing criteria.

Though NIOSH indicates that the experience level of the analyst performing the fiber count does not significantly contribute to variations. Novice or untutored fiber counters who work only from published instructions often obtain fiber counts that are as little as half of those obtained by experienced fiber counters. Therefore, it is strongly recommended that formal training be a part of the operation. Introductory and continuing training programs are offered by a number of organizations; published notices frequently appear in the professional literature (i.e., the Journal of the Air Pollution Control Association and the American Industrial Hygiene Association Journal).

It should be noted that a number of commercial laboratories offer analytical services for user-supplied filter samples. The American Industrial Hygiene Association maintains a laboratory accreditation program and periodically publishes a list of accredited laboratories in its journal. Accredited laboratories are required to participate in the NIOSH Proficiency Analytical Testing Program (PAT), which requires analysis of PAT-supplied material.

Electron Microscopy and X-Ray Diffraction

Greater specificity and accuracy in fiber measurements can be gained by examining the morphology and structure of individual fibers through electron microscopy or by determining fiber composition through X-ray diffraction. As with optically analyzed samples, fibers are collected onto membrane filters. However, sample preparation is much more complex, and the analytical equipment requires trained personnel. These techniques, though much more expensive than optical counting, do address fibers of all sizes, and provide a mineral-specific exposure assessment.

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